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*BOILING POINTS OF NAPHTHALINE, BENZOPHENONE, AND BENZOL UNDER CONTROLLED PRESSURES, WITH SPECIAL REFERENCE TO THERMOMETRY.**

BY S. W. HOLMAN, S.B., AND W. H. GLEASON, S.B.

THE employment of the melting and boiling of various substances as a means of testing or of graduating thermometers at temperatures above 100° C. is a practice of long standing, especially among chemists. But it will be readily conceded that the results have been in general but roughly approximate, owing to several causes of error, *e.g.* imperfect purification of substances, faulty apparatus (permitting under or over heating), incomplete systems of thermometry, and errors in the values assumed as the melting and boiling temperatures, these arising, in turn, from causes similar to those just mentioned.

The value of steam as a means of fixing one point on the thermometric scale comes in part from the facts that water does not change composition on boiling at ordinary pressures; that it can be readily obtained in a state of sufficient purity, so that the temperature of its vapor, or rather of a clean thermometer placed in its vapor, can be relied upon as sensibly reproducible under a given pressure; and that this temperature under more than the ordinary range of atmospheric pressure has been measured (by Regnault and Magnus) with sufficient accuracy for thermometric uses. The primary measurement of temperatures

* Read before the American Academy of Arts and Sciences, January 11, 1888.

above 100° C. is a process of extrapolation from the ice and steam points, and thus possesses the liability to error common to all extrapolation, the magnitude of the error depending upon the method, instruments, and skill employed. It is obvious, therefore, that, whatever be the system of thermometry, a decided gain in accuracy and convenience would accrue to the art of temperature measurement, if by competent investigation other substances could be had which at other temperatures should fulfil the conditions just named as rendering steam so useful.

The investigations in this direction by Prof. J. M. Crafts — in part published * — contribute far more than any others to the establishment of such fixed reference temperatures. The results of Mill's † measurements of melting points are also important. Independent study of the same substances by various observers is valuable, even when the check results cannot claim all the accuracy of the most elaborate investigations. For it is of material importance to answer in this way, for each substance, the questions: Is the substance reproducible with sufficient certainty to give wholly independent workers sensibly the same temperature? What is this temperature in absolute degrees (of Thomson scale) as a function of the vapor pressure, errors in thermometric methods being eliminated? Is the substance readily reproducible without prohibitive expense?

The following is a brief account of a study of naphthaline, benzophenone, and benzol, undertaken with these points in view, and with special reference to attempting to check the results of Professor Crafts. It is probable that, owing to superior facilities and greater experience, he has obtained results entitled to decidedly greater weight than those which we give. But it is believed that the conditions under which our work was done, and the pains taken in the system of air thermometry, entitle the temperature measurements to consideration.

In designing the apparatus we departed somewhat widely from the published descriptions of Crafts's apparatus in almost all details. Our thermometer contained air dried and freed from CO_2, while Crafts's contained hydrogen; its bulb was large (about 200 cc.); the substances studied were either commercially obtained or prepared by methods differing from those of Crafts; and the vapor pressures were under control by a regulator, and were extended through a greater range. We have since learned from Professor Crafts that the form of gas thermom-

* Crafts. Bulletin de la Soc. Chim., xxxix. 196, 277 (1883).
† Mills. Phil. Mag., (5), xiv. 1 (1882).

eter whose description had been published was not invariably employed, but that others of various capacities and forms had been used.

The concordance of our results with those of Professor Crafts for naphthaline (p. 10) is certainly as close as could be anticipated, and is within the limits of error in even the most elaborate use of the mercurial thermometer at those temperatures. For benzophenone (p. 10) the accordance is from 0°.3 to 0°.5 C., — a difference possibly arising from errors in thermometry introduced by difficulties met with on our part from somewhat irregular action of the kind of glass which we were forced to employ in our air thermometer bulb, and which rendered the determination of its coefficient of expansion somewhat less satisfactory at this higher temperature than at lower ones. Yet we think the difference too great to be wholly accounted for by thermometric errors.

The results of the investigation may be summarized as follows: —

1. **Naphthaline,** $C_{10}H_8$, is readily obtainable in a state of sufficient purity to give a reference temperature exact within 0°.1 C. We have found a preparation melting at 79°.4 to 79°.8 to possess a boiling point within the ordinary range of atmospheric pressure (H), expressible by

$$t^\circ = 218.07 + 0.0625\ (H - 760),$$

where H is the reduced pressure in "normal" millimeters of mercury. Throughout the paper the degrees and pressures may be regarded as "normal," *i.e.* corresponding to the definitions adopted by the International Bureau of Weights and Measures, "Trav. et Mém.," i. (1881). No reduction for gravity has been made, because the correction at Boston is below the limits of error of this work.

2. **Benzophenone,** $(C_6H_5)_2CO$, is obtainable with some difficulty, and is rather costly. With a melting point of 47°.6 to 48°.0 our determination of the boiling point within the ordinary range of atmospheric pressures is expressible by

$$t^\circ = 305.6 + 0.060\ (H - 760).$$

3. **Benzol,** C_6H_6, is readily obtainable nearly pure. Anhydrous benzol melting at 4°.22 was found to have a boiling point expressible within the ordinary range of atmospheric pressures by

$$t^\circ = 80.19 + 0.0455\ (H - 760).$$

4. The boiling points for pressures down to 80 mm. for naphthaline and benzophenone, and to 360 mm. for benzol, are tabulated on page 11. No attempt has been made to express the vapor pressure as a

function of the temperature through these greater ranges by any of the numerous formulæ employed by others for this purpose.

5. We regard the actual errors in the final results for the naphthaline and benzol at the atmospheric pressure as under 0°.1, and that for the benzophenone as under 0°.25. The average deviation of the single observation from the curves upon which the tabular values were interpolated were: naphthaline 0°.1, benzophenone 0°.3, benzol 0°.06.

6. The device used by us for controlling the pressure is easily adjustable, and sufficiently constant to afford, in connection with the substances which we have investigated, a means of obtaining exactly any desired temperature within the range measured. Thus this or a similar apparatus may serve for testing mercurial thermometers at several points, or for maintaining adjusted and known temperatures for other purposes.

AIR THERMOMETER.

Primary temperature measurements to be reducible to the absolute scale (Thomson's) must be made by a gas thermometer, and the air thermometer is the most available. The Jolly* form, in which the closed and open arms of the manometer are connected by a flexible tube, is the most convenient, and was adopted in this work. The difference of level of the mercury surfaces was, however, measured by a special device. Vertically between the two arms of the mercury column is placed a steel millimeter scale of 1.3 cm. square section, and with straight edges. A T-square with double blade is held by the hand firmly against the scale edge, and the blades, which project across the face of the scale, pass, one behind, the other in front of the mercury column. The square is then slid up or down until the plane of the lower edges of the blades is tangent to the top of the meniscus, just as in setting a barometer vernier. By placing the tubes so that there is a bright light behind them, differences of level of the columns can be read with errors of less than one-tenth of a millimeter, the tenths being estimated. The bulb used was about 15 cm. long, 4.5 cm. in diameter, and 0.5 to 1 mm. thick, with a capacity of about 200 cc., and the volume of projecting stem was but 0.64 cc. The glass bulb and tube were continuous over to the three-way cock to which the flexible tube was attached. The glass gauge tubes were about 1 cm. inside diameter. The gauges, scale, etc., were carefully protected from heating, and their temperatures obtained by suitably disposed thermometers. The bulb was filled and emptied many times at 100°. The air was thoroughly dried by calcic chloride,

* Pogg. Ann., Jubelband.

sulphuric acid, and phosphoric anhydride, and its carbon dioxide was removed by sodic hydrate. Two determinations of its coefficient of expansion made one before and one after the measurements on naphthaline, gave 0.00 366 95 and 0.00 366 87, of which the mean, 0.00 366 91, was employed. Other values are:—

Regnault	0.00 366 82
Magnus	365 10
Jolly	367 28
Rowland	367 13
Mean	0.00 367 08

With this mean the above value is in so close accordance as to show that the apparatus and coefficient of expansion of glass used must be sensibly correct. The formulæ used in computing a and temperatures was that given by Rowland.*

The coefficient of expansion of the glass bulb of the air thermometer was obtained by a weight thermometer made from the same piece of tubing. Both bulbs were made of the full diameter of the original tube, and with no further heating than was necessary to close the ends. They were thus both of the same diameter and thickness, and had been subjected to substantially the same treatment. In the computations, the values of the coefficient β, used for mercury, were those of Wüllner's recomputation of Regnault's experiments. Measurements were made in vapor of benzophenone, naphthaline, aniline, and water, a special double-jacketed heater being employed. The results were:—

Temp. °	β_t used. (Wüllner.)	κ obtained.
306	0.00 018 667	0.00 003 004
306	667	3 012
218	468	2 895
184	401	2 830
100	253	2 700

The values of κ used for the benzol measurements were determined by Mr. W. S. Hadaway, Jr., on glass of the same kind, at temperatures below 100°. The results overlap at 100°, and are sensibly in accord. In some preliminary work, with bulbs carefully annealed before and after having been filled with mercury, values of κ up to 218° were obtained which are in close agreement with the foregoing. The bulbs were all filled by boiling the mercury in them. This mercury and that used in the gauges was redistilled in the laboratory.

* Proc. Amer. Acad., xv. 98 (1880).

The capillary leading from the air thermometer was as fine as possible, and special care was taken to obtain accurately the temperature of the air in the exposed stem of the thermometer.

BOILING POINT APPARATUS.

Upon a horizontal circular brass disk of 18 cm. diameter was brazed, with a heavy collar, a vertical thin brass tube 7.8 cm. diameter and 37 cm. high. Eccentrically within this stood a similar tube 6.5 cm. diameter and 34 cm. high, being held in place simply by its weight and by a thin brass collar so near the bottom as to be beneath the surface of the liquid when boiling. Notches cut into the lower edge of the inner tube allowed the vapor formed under this collar to pass into the inner, not into the outer space. A vertical brass tube, open at both ends, about 100 cm. long and 2 cm. diameter, passed through the cover at one side, and extended (by a removable portion) in the outer space of the boiler nearly to the surface of the liquid. This served as an escape and condenser tube, and to its top was attached the exhaustion tube when pressures other than the atmospheric were desired. Outside this a glass condenser was placed for water circulation when benzol was used: with naphthaline and benzophenone this outer jacket was removed. The height to which the vapor extended in the tube could be ascertained by passing a moist cloth along it, and could be readily maintained nearly constant by adjusting the gas flame beneath the boiler. The cover was a brass casting turned and ground to fit a brass ring brazed to the top of the outer tube of the boiler. It was secured to the ring by six screws, and the joint was always very nearly vapor-tight. Through the top were four borings; one nearly central to admit the stem of the air thermometer, three for the insertion of mercurial thermometers to be compared with the air thermometer. These borings were closed by perforated screw-plugs, of which the central one was split lengthwise so that it could be placed on the air thermometer stem after this had been passed through the larger hole in the cover. Leakage was reduced to a minimum by an asbestos packing. Thus, when the liquid was boiling, the circulation of vapor was up the inside tube, in which the mercurial and air bulbs were located, down the jacketing space between the tubes, and up into the condenser tube until liquefied, whence it would drip back into the boiler. The depth of liquid in the boiler was from 2 to 5 cm. The sides and top of the boiler were covered with hair felt from one to three inches thick.

The whole instrument was mounted upon a strong wooden frame in such a way that the cover of the boiler, having the air thermometer

rigidly attached to it by a brass bracket, was fixed in place, while the boiler was removable.

For testing mercurial thermometers in the vapor of substances boiling at high temperatures, the following apparatus has been employed. It is similar to the boiler of the larger apparatus. Into the bottom of a thin brass tube, of about 5.3 cm. diameter and 20 cm. high, is brazed a thicker plate. Within this tube stands a shorter tube of about 4.5 cm. diameter notched at the bottom edge, and having a somewhat eccentric collar at about 2 cm. from the bottom, to hold it in place and prevent the vapor from freely rising into the outer jacket. The cover fits with a flange into the top of the outer tube and is split along a diameter. The boring for the insertion of the thermometer is in the centre. Through one-half of the cover passes a thin tube about 60 cm. long and 1 cm. internal diameter, projecting about 15 cm. below the cover. This lower portion thus extends nearly to the surface of the liquid in the outer jacket, being placed of course in the larger side of that jacket, and serves as an escape or condenser tube.

PRESSURE REGULATOR.

This has been elsewhere described in full,* and is shown in the figure. A Richards water-jet aspirator drew air from *a*, and *c* was connected with the apparatus to be exhausted. The small glass tube *efp* was drawn out to an open point at *p*. As the exhaustion proceeded, the mercury rose in the large glass tube *j* and in *f*, until the level in the open cistern *gh* fell below *p*, whereupon the mercury in *f* would flow over into *j*, followed by a sudden inrush of air, thus increasing the internal air pressure and causing the mercury to fall somewhat in *j* and rise at *gh*, thus closing *p*. Repetitions of this process would occur until a steady condition was reached, when a nearly regular stream of air and mercury globules would flow continuously through *f*. To maintain steady action, proper relative sizes of tubes and openings must be discovered, and some constriction should be placed in *ij*, and a vessel of large capacity should be present in the circuit. The amount of exhaustion can of course be regulated by the quantity of mercury in the cistern, and by the lengths of the tubes. The pressures were measured by a separate mercury column and the barometer.

* Proc. Amer. Acad., xxi. 1 (1885); Technology Quarterly, i. (1886).

INSTRUMENTAL ERRORS.

The barometer was one which had been compared directly with another which had been studied somewhat by a cathetometer, and by comparison with a Signal Service standard in Boston. Its constant error must have been reduced to a fraction of a millimeter, which, so far as it is constant, would not sensibly affect the temperature measurements. Scales were by Brown and Sharpe, of Providence, R.I., and had no errors sensible in this work as compared with a standard scale by Prof. William A. Rogers. Thermometers used were corrected. Those for the more exact work were by Baudin, of Paris, and were read to fiftieths of a degree. Pernet's method of thermometry was employed. Calibration and stem exposure corrections were applied. A more extended discussion than has been published, so far as we are aware, as to the precision necessary in the component measurements entering into the air thermometry, was made with a view to best proportioning of parts and the elimination of determinate constant errors.

PREPARATION OF SUBSTANCES.

This was done by Mr. Gleason, under the direction of Prof. L. M. Norton and Mr. C. W. Andrews of the Chemical Department of the Institute.

Naphthaline. — The pure product from Kahlbaum, of Berlin, was used without subsequent treatment. Samples were fractionated, and all distilled within 0°.3. These distillates were kept separate, each being divided into as many parts as there were tenths rise in temperature, and the melting points of all were found the same. The range of melting and solidifying points of the naphthaline, as taken from the original package, was 79°.38 to 79°.68; after use through the entire series of observations in the boiling-point apparatus it was 79°.42 to 79°.84.

Benzophenone. — The method of Friedel, Crafts, and Ador * was at first selected, on account of its apparent simplicity and the ease of production of considerable quantities of the substance in the pure state. For reasons not known, the rate of production was too small; and the process was abandoned in favor of that of Chancel,† namely, the dry distillation of benzoate of calcium. The benzoate was prepared by neutralizing an aqueous solution of benzoic acid with milk of lime. When litmus paper gave the neutral reaction, the liquid was filtered hot, evaporated, crystallized, and dried, the mother liquor being evap-

* Comptes Rendus, xxxv. 673. † Liebig's Ann. d. Chemie u. Pharm., lxxii. 279; lxxx. 285.

orated to dryness, and the salt dried. This gave a white product with very little loss. 2500 grams of calcium benzoate were subject to dry distillation, and 820 grams of the crude product were obtained. This liquid was of a dark red color, and 608 grams of it boiled above 200°. The result of fractionation was a straw-colored liquid, which would not solidify by cooling even to $-15°$ C.; but on the addition of a very minute crystal of benzophenone the whole solidified suddenly. This product was again fractionated, and all below 280° rejected. After three recrystalizations from a mixture of alcohol and ether, 500 grams of pure benzophenone were obtained, which, after being dried, melted at 46°.74 to 47°.72; a recrystallization gave the same; but after carrying the benzophenone through the entire series of observations in the boiling-point apparatus, its melting point was 47°.62 to 48°.02, and it solidified at 47°.7, indicating that the initial melting points were probably lowered by presence of alcohol or ether.

Benzol. — The Kahlbaum product was tested for thiophene with isatine, and was shaken with P_2O_5 and distilled. This product melted at 4°.22, and was used in the measurements.

RESULTS.

The direct results obtained will be now given, with deduced formulæ and tables. On page 11 is a table interpolated for each 2 cm. pressure for each substance. In the interpolation for these, an application of the method of residual curves greatly facilitated the work. Each table of observations contains two or more series. Columns headed p give measured pressures in millimeters within the boiler; those headed t give the corresponding temperatures measured by the air thermometer. The correction to reduce the air thermometer to absolute scale is smaller than the limits of error of this work, and has therefore been omitted

NAPHTHALINE.

Observed Pressures and Temperatures.

p. mm.	t. °	p. mm.	t. °
759.8	218.11	84.8	141.94
762.7	218.29	141.4	155.57
713.3	215.20	234.8	172.12
655.9	211.59	336.1	184.83
555.7	204.61	461.0	197.02
454.4	196.34	546.7	203.91
352.2	186.39	638.1	210.31
242.5	172.75	711.0	215.00
130.2	152.38	759.0	217.84

Within the limits of 730 and 760 mm. the temperature varies almost directly as the pressure, so that the expression

$$t° = 218.07 + 0.0625\ (H - 760)$$

serves to give the boiling point of naphthaline under any ordinary atmospheric pressure, H, expressed in normal millimeters of mercury. This and subsequent similar ones may probably be used safely up to 780 mm. The following table serves to compare our results with those of Crafts.

p. mm.	t, Crafts. °	t, H. and G. °
720.39	215.7	215.60
730.31	216.3	216.21
740.35	216.9	216.84
750.50	217.5	217.48
760.74	218.1	218.12

[N.B. — In Crafts's original tables appear the erroneous values 753.90–217°.8, 755.31–217°.9. These pressures should be about 755.60 and 757.31, respectively, as inspection will show.]

BENZOPHENONE.

Observed Pressures and Temperatures.

p. mm.	t. °	p. mm.	t. °
755.1	305.34	104.3	223.60
698.1	301.69	220.2	251.92
644.1	298.08	314.3	265.56
527.7	288.61	445.2	280.93
432.5	280.14	580.5	292.56
318.1	266.52	660.0	299.19
201.2	250.58	739.9	304.76
88.9	219.59	....	....

Comparison with Crafts's Results.

p. mm.	Crafts. °	H. and G. °
732.38	304.3	303.94
740.06	304.8	303.41
750.91	305.5	305.05
760.32	306.1	305.62

Between 720 and 760 mm. the following expression applies to express the boiling point as a function of vapor pressure:—

$$t° = 305.6 + 0.060\ (H - 760).$$

BENZOL.

Observed Pressures and Temperatures.

p. mm.	*t.* °	*p.* mm.	*t.* °
769.8	80.65	400.7	60.57
733.6	78.71	351.7	57.34
698.7	77.43	352.9	57.63
660.1	75.70	448.8	63.90
608.8	73.11	589.9	72.13
554.7	70.42	652.5	75.52
518.8	68.54	730.1	79.09
454.6	64.78	768.8	80.57

Between 720 and 780 mm. the following expression applies: —

$$t° = 80.19 + 0.0455\ (H - 760).$$

Boiling Points from 8 cm. to 76 cm.

Press. *p.* cm.	Naphthaline. *t.* °	Benzophenone. *t.* °	Benzol. *t.* °	Press. *p.* cm.	Naphthaline. *t.* °	Benzophenone. *t.* °	Benzol. *t.* °
8	140.84	216.0	....	44	195.07	280.4	63.57
10	145.84	222.8	....	46	196.89	282.4	64.90
12	150.54	229.2	....	48	198.59	284.3	66.20
14	154.86	235.0	....	50	200.24	286.2	67.42
16	158.70	240.4	....	52	201.85	287.9	68.58
18	162.48	245.1	....	54	203.40	289.7	69.66
20	166.10	249.1	....	56	204.92	291.5	70.70
22	169.46	252.6	....	58	206.42	293.2	71.70
24	172.67	255.8	....	60	207.88	294.8	72.66
26	175.48	258.7	....	62	209.30	296.4	73.64
28	178.10	261.4	....	64	210.63	297.8	74.60
30	180.58	264.0	....	66	211.86	299.2	75.57
32	182.93	266.6	....	68	213.10	300.5	76.53
34	185.17	269.1	....	70	214.35	301.8	77.47
36	187.28	271.6	58.00	72	215.58	303.1	78.37
38	189.32	273.9	59.40	74	216.80	304.4	79.28
40	191.29	276.1	60.77	76	218.07	305.6	80.19
42	193.20	278.3	62.17	78	....	....	81.10

This investigation constituted the thesis work of Mr. Gleason, and the experimental work was very largely conducted by him alone. The expense attending the work has been met in part by an appropriation from the Rumford Fund of the American Academy of Arts and Sciences, in part by the Institute.

ROGERS LABORATORY OF PHYSICS,
August, 1887.

EXPERIMENTS RELATING TO THE THEORY OF BEAMS.

By JEROME SONDERICKER, C.E.

While the common theory of beams gives fairly satisfactory results within the elastic limit of iron and steel, at the point of rupture, as is well known, it does not reasonably accord with the known strength of the material as determined by actual trial. In illustration of this lack of agreement, we may cite the following cases, beams of rectangular cross-section alone being referred to:—

Cast Iron. — It is well known that the modulus of rupture, computed by the ordinary formula, is, for a rectangular bar of cast iron, about double the tensile strength of the material.

Steel. — Bauschinger's experiments on rectangular beams of Bessemer steel, published in "Mittheilungen aus dem Mechanisch-Technischen Laboratorium der K. Technischen Hochschule in München," 1874, furnish very complete information regarding the resistance of such beams. The experiments were performed upon bars of Bessemer steel, 5.5 cm. wide by 14 cm. deep by 120 cm. long, the span being one meter. The following table of results is copied from this article:—

Per Cent Carbon.	Elastic Limit. Kilos. per square cm.		Ratio.	Maximum Strength. Kilos. per square cm.		Ratio.
	Tension.	Bending.		Tension.	Bending.	
0.14	2950.	3750.	1.27	4430.	7920.*	1.78
0.19	3310.	4170.	1.26	4785.	8600.*	1.79
0.46	3450.	4030.	1.17	5330.	8340.	1.56
0.51	3405.	4170.	1.22	5600.	9300.	1.66
0.54	3490.	4030.	1.15	5530.	8500.	1.53
0.55	3300.	4240.	1.28	5650.	8825.	1.58
0.57	3310.	4450.	1.34	5670.	9600.	1.69
0.66	3745.	4380.	1.17	6295.	8600.	1.36
0.78	3750.	4650.	1.24	6470.	8750.	1.35
0.80	4005.	4725.	1.18	7230.	7645.	1.06
0.87	4290.	4700.	1.10	7355.	7650.	1.04
0.96	4870.	6950.	1.42	8305.	8480.	1.02

* Not broken.

Wrought Iron. — Experiments indicate that wrought iron behaves similarly to mild steel in its resistance to bending.

Although a great many different explanations have been offered to account for this disagreement between theory and experiment, the matter is still unsettled. The experiments which have been made with reference to the subject are not, as a rule, sufficiently exhaustive. In order to throw additional light upon this important subject, there was performed by the writer of this article, in the Applied Mechanics Laboratory of the Massachusetts Institute of Technology, during the winter of 1887–8, a series of experiments which will here be explained.

It may be stated at the outset that the theory which it was the object of these experiments to test, and which they tend to substantiate, is the following: The direct stress, tension, or compression, at any point of a given cross-section of a beam, is the same function of the accompanying strain as in case of the corresponding stress when uniformly distributed. This theory has been hinted at, more or less definitely, by various writers. At the time of performing these experiments the writer was not aware that any attempt had been made to test the theory just stated by experiment. Since then, however, his attention has been directed to a memoir by M. Considère, published in the "Annales des Ponts et Chaussées," for April, 1885, which describes some experiments bearing on the same subject. The conclusions arrived at by this experimenter substantially accord with the results of the experiments to be described.

EXPLANATION OF EXPERIMENTS.

Altogether five beams were experimented upon, three being of cast iron, one of Bessemer steel, and one of wrought iron. Four of these beams were of rectangular cross-section, approximately three inches deep by one inch wide; the remaining one was of T section. All the cast-iron beams were planed; the wrought-iron and steel beams were not planed. The experiments were conducted as follows: —

Before testing, a length of about 15 inches was cut from one end of each of the beams. From these were cut tension and compression specimens, the tension specimens being taken from the side corresponding to the tension side of the beam, and the compression specimens from the opposite side; this precaution being taken in order to provide as nearly as possible for any lack of homogeneity in the beams. These tension and compression specimens were tested in the ordinary manner, the elongations and compressions being measured to ten-thousandths of

an inch. In the case of the tension specimens these measurements were continued as nearly as possible up to the breaking point. In the case of the compression specimens the measurements were carried on until the test piece began to deflect sideways, or up to the full capacity of the testing machine.

The beams were loaded and supported as shown in Fig. 1. As will be seen from this figure, the pressure was applied equally at two points equidistant from the centre of the beam. One of the supporting knife edges rested on small steel rollers. Rollers were also introduced at the points (*A*, *A*); thus, neglecting the rolling friction, all the external forces remained vertical throughout the test. The reason for the introduction of the central rollers is plain. That it is also important, in order to obtain accurate results, to allow the span to change freely,

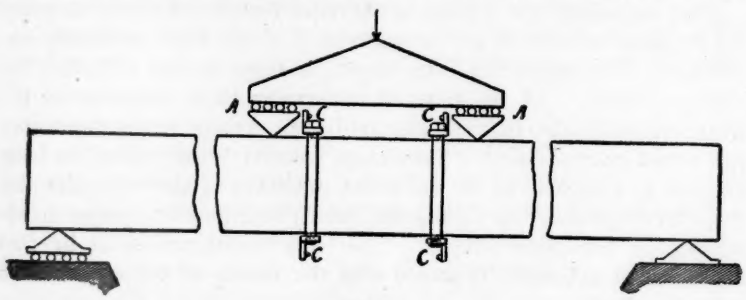


Fig. 1.

may be better appreciated by reference to a few observations made in connection with these experiments. In the case of cast-iron beam No. 2, the original span was $30\frac{1}{2}$ inches; with a load of 2100 lbs. this changed to $30\frac{33}{64}$ inches, with a load of 4100 lbs. to $30\frac{34}{64}$ inches, and with a load of 7600 lbs. to $30\frac{38}{64}$ inches, in the last case an increase of $\frac{5}{32}$ of an inch. In the case of the Bessemer steel beam the original span was $36\frac{1}{2}$ inches; at the conclusion of the test it was $36\frac{3}{32}$ inches, a decrease of $\frac{5}{32}$ of an inch. The span of this beam first increased as in the case of the cast-iron beam, and afterwards diminished as the deflection became considerable. If the beams had rested on fixed supports, it is evident that either they would have slipped on the supports, or the supports would have yielded, or horizontal external forces would have been introduced in addition to the vertical forces measured by the testing machine. Most probably a combination of these results would have occurred; at any rate, the actual bending moment would have been rendered somewhat uncertain.

When a beam is loaded in the manner indicated, its weight being neglected, we know that the portion included between the centre knife edges is subjected to a uniform bending moment; also that the shearing stress is zero, and the deflection curve a circular arc. From the fact that the bending moment is constant, it follows that the intensity of the stress to which any one fibre is subjected is also constant; hence we can measure the amount of extension and compression of the extreme fibres in a manner similar to that employed in direct tension and compression tests, of course making proper allowance for the curvature of the beam. There being no shearing stresses in the portion of the beam referred to, our attention can be wholly given to the direct stresses. Thus the investigation is made as simple as possible.

The extension and compression of the fibres was determined by means of the two clamps shown in the figure. These clamps were attached to the beam at a known distance apart, being furnished with conical points for this purpose. By calipering between the projecting points (C, C) with a micrometer caliper the change in their distance apart was determined. Throughout this investigation the assumption is made that a plane cross-section remains plane after bending. No valid objection can be made to this assumption in the case at hand; for, if we imagine the portion of the beam which is to be subjected to a uniform bending moment divided by a series of equidistant cross-sections, these divisions will be equally distorted when the beam is loaded, since they are under identical conditions of stress. This would not be the case if the cross-sections ceased to be plane. We can determine by means of the measurements taken between the projecting points on the clamps, the radius of curvature of the beam, and, making proper correction for the curvature, the position of the neutral axis and the strain at any distance from this axis. In each of the beams tested, the load was increased by equal increments, and the position of the neutral axis and strains in the extreme fibres determined for each successive load. The measurements were carried as nearly as practicable up to the breaking point in the case of the cast-iron beams, and until the deflection became excessive in the case of the wrought-iron and steel beams.

We have now obtained all the data necessary to test the theory proposed, for the tension and compression tests determine the relation existing between the stresses and strains, while the beam tests supply a knowledge of the strains in the beams resulting from any given load. Thus we can determine the stresses in the beams due to a given load, and from these stresses can calculate the magnitude of the resisting

moment, for comparison with the actual bending moment to which the beam was subjected. We can also determine from the tension and compression tests, the position of the neutral axis of the beam for comparison with its position as determined by direct experiment. In order to make these comparisons the results of the tension and compression tests were represented by stress-strain diagrams in the usual manner, the ordinates representing the stresses per unit area of cross-section and the abscissas the elongations or compressions per unit length. We will first refer to the determination of the position of the neutral axis by means of these diagrams. It is well known that the direct stresses at any cross-section of a beam are subject to the condition that the total tensile stress must equal the total compression stress. Let the curve *OA*, Fig. 2, represent a tension diagram, and *OD* the corresponding compression diagram. If we erect any ordinate as *CA*, the area included by this ordinate, the curve, and the axis of abscissas can be taken to represent the total tensile stress at a cross-section of a rectangular beam, corresponding to a tensile strain *OC* in the extreme fibre. If we now erect the ordinate *BD* in the compression diagram so as to include an equal area, this area will represent the corresponding total compression stress, and the neutral axis will divide the depth of the beam into parts proportional to *OC* and *OB*. In this manner the positions of the neutral axis corresponding to the measured tensile strains in the extreme fibres were determined when the beam was of rectangular cross-section. For a section of variable width this method must be somewhat modified. The positions of the neutral axis, determined in the manner indicated, are recorded in the second column of the tables given at the end of this article, for comparison with their corresponding positions determined by direct experiment and recorded in the third column.

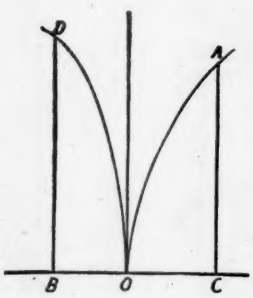


Fig. 2.

The determination of the values of the bending moments from the stress-strain diagrams is based upon the well-known principle that the moment of the direct stresses must equal the moment of the external forces. The method consisted in laying off areas corresponding to the measured tensile and compressive strains in the extreme fibres of the beam, in the manner described above, and finding the moments of these areas with reference to the axis of ordinates. The sum of these

moments, when reduced to the proper unit, is the moment of the direct stresses, if the theory proposed is correct, and should equal the corresponding moment of the external forces. The results obtained from the diagrams are given in the fourth column of the tables for comparison with the actual bending moments to which the beam was subjected, recorded in the fifth column.

The sixth column gives the values of the bending moments, as computed by the ordinary formula, which are necessary to produce the tensile stresses determined from the diagrams and recorded in the seventh column.

The seventh and eighth columns give the tension and compression stresses corresponding to the measured strains in the extreme fibres of the beam; these stresses being determined from the stress-strain diagrams. The ninth column gives the maximum fibre stress in the beam as computed by the ordinary formula.

The diagrams in Plates I. and II. are given in order to present more clearly the results contained in the tables. In Plate I. the heavy horizontal lines represent the position of the centre of gravity of the cross-section of the beams, the space above these lines corresponding to the compression side. The points connected by the full lines represent the successive positions of the neutral axis as determined by direct measurement; the points connected by the dotted lines, their corresponding positions as determined from the diagrams. In the diagrams of Plate II. the ordinates of the points lying on the straight, inclined line represent the bending moments to which the beam was actually subjected; the ordinates of the points connected by the dotted lines, their values derived from the diagrams, while the ordinates of the points connected by the broken lines represent the values recorded in the sixth column of the tables.

It will be seen from an examination of the tables and diagrams that the positions of the neutral axis as determined experimentally, and from the stress-strain diagrams, coincide more nearly as the bending moment increases. Provided that the theory tested be correct, this is to be expected; for the errors of observation will affect the minute strains occurring at the beginning of the tests to a greater extent than the larger strains resulting from the heavier loads. The internal stresses existing in the beams might also affect the results somewhat. It will also be noticed that in the case of the cast-iron beams the actual bending moments are uniformly greater than those determined from the diagrams. This may possibly be due to the fact that in the tension and compression tests the average strength of the cross-section is

determined, while in the beam tests the stronger metal at the surface of the beams will have greater influence. Taking into account the minuteness of the observed strains and the variable strength of the tension specimens cut from the same bar, these experiments furnish strong evidence in favor of the proposed theory.

Strictly, the actual cross-sections of the beams and tension and compression specimens, while under strain, are the proper ones to use in this investigation, instead of the original dimensions which were used. However, within the limits of strain covered by these tests the difference between the results obtained by using the original and distorted sections is unimportant. If we take, for example, the case of the steel beam, the effect of using the actual instead of the original cross-section would be to move the neutral axis, determined from the diagrams, slightly towards the tension side of the beam, the change in its position for the largest strain involved (5½%) being between 0.01 and 0.02 inches. The value of the bending moment would not be appreciably altered. M. Considère concludes from his experiments, described in the memoir already referred to, that by using the actual distorted sections in the computations, the theory that the direct stresses in a bent beam are the same function of the strains as in case of the same stresses produced in direct tension and compression tests, holds good even up to the point of rupture of beams of wrought iron and soft steel.

VARIATION OF THE MODULUS OF RUPTURE WITH THE FORM OF CROSS-SECTION OF A BEAM.

Since, according to the proposed theory, the material near the neutral axis of a beam offers greater proportional resistance to bending, when the beam is strained beyond the elastic limit, than is assigned to it by the common theory, it would follow that the ratio of the modulus of rupture, computed by the common theory, to the tensile or compressive strength of the material ought to be greater, the greater the amount of material massed at the neutral axis, and that this ratio ought to approach unity in the case of such sections as I sections where there is comparatively little material near the neutral axis. In this respect the proposed theory agrees with the results of experiments. We will refer first to cast iron. Major Wade, in his "Report of Experiments of Metals for Cannon," remarks with reference to experiments performed by him at the South Boston foundry, to determine the transverse strength of different kinds of cast iron, and in which he tested both round and square bars, as follows: "The formula by which the

strength of the round bars is computed appears to be not quite correct, for the unit of strength in the round bars is uniformly much higher than in the square bars cast from the same kind of iron." Facts of a similar nature have been frequently noted and commented upon. In Hodgkinson's experiments on cast-iron beams, the modulus of rupture of I and T sections agrees more closely with the tensile strength of the material than in the case of rectangular bars. The following table (p. 20) gives the results of a number of tests of the transverse strength of cast-iron beams of different forms of cross-section.

The ratio of the modulus of rupture to the tensile strength will, of course, vary considerably with the proportions used, in the case of such sections as I and T sections; and even when identical forms are employed this ratio will vary with the quality of the iron. Thus it will be noticed in M. Considère's experiments that the ratio is less in the case of the iron having a high tensile strength than in case of the weaker metal; and we saw in Bauschinger's experiments that in case of rectangular bars, at least, the same thing is true for steel. While it is valuable to know that the theory agrees in a general way with the results of experiments upon the transverse strength of beams of different form of cross-section, numerical comparisons are desirable. For the purpose of making such a comparison, the writer calculated from the stress-strain diagrams of cast-iron beam No. 3 the values of the moments of rupture of beams of this iron of round, square, and I sections. Their moduli of rupture were computed from these moments of rupture in the ordinary way, and the following values found for the ratio of the modulus of rupture to the tensile strength of the iron, — for a round bar, 1.77; for a square bar, 1.63; and for the I section, 1.37. These agree very well with the results contained in the table, with the exception of the circular section, where the ratio is smaller than any of those given in the table for this form of section. The suggestion already offered in explanation of the fact that, in the writer's experiments on cast-iron beams, the bending moments determined from the stress-strain diagrams are slightly less than the actual bending moments to which the beams were subjected, applies equally here.

Fewer experiments have been made with wrought-iron and steel beams, to determine the effect of variation in the form of cross-section on the modulus of rupture, than with cast-iron beams. These are, moreover, more difficult to compare, as I and similar beams of wrought iron and mild steel usually give way by buckling, at a load apparently somewhat lower than they would otherwise bear. However, it is well known that while the modulus of rupture of round and square bars of

Form of Beam Section.	Tensile Strength. lbs. per sq. in.	Modulus of Rupture. lbs. per sq. in.	Ratio.	Condition of Specimen.	Experimenter.
	19850.	41320.	2.08	Turned.	C. Bach.*
	16070.	35500.	2.21	Turned.	Considère.†
	34420.	63330.	1.84	Turned.	Considère.
	24770.	54390.	2.19	Turned.	Robinson and Segundo.‡
	25040.	46280.	1.85	Rough.	Robinson and Segundo.
	Mean.		2.03		
	16070.	29250.	1.82	Planed.	Considère.
	36270.	58760.	1.62	Planed.	Considère.
	19090.	33740.	1.77	Planed.	C. Bach.
	Mean.		1.74		
	19470.	34060.	1.75	Planed.	C. Bach.
	31430.	49030.	1.56	Planed.	Considère.
	19880.	33860.	1.70	Planed.	Sondericker.
	24770.	42340.	1.71	Planed.	Robinson and Segundo.
	25040.	42110.	1.68	Rough.	Robinson and Segundo.
	Mean.		1.68		
	19470.	28150.	1.45	Planed.	C. Bach.
	16070.	22500.	1.40	Planed.	Considère.
	31860.	36640.	1.15	Planed.	Considère.
	25040.	31310.	1.25	Rough.	Robinson and Segundo.
	Mean.		1.31		
	16070.	23780.	1.48	Planed.	Considère.
	31290.	34730.	1.11	Planed.	Considère.
	18050.	24550.	1.36	Planed.	Sondericker.
	22470.	26150.	1.16	Rough.	Burgess and Vielé.§
	Mean.		1.28		

* See "Zeitschrift des Vereines Deutscher Ingenieure," March 3d and 10th, 1888.
† See "Annales des Ponts et Chaussées," 1885.
‡ See "Proceedings Institute of Civil Engineers," Vol. 86.
§ Thesis, — "The Tensile and Transverse Strength of Cast Iron." Mass. Inst. Tech.

wrought iron and mild steel greatly exceeds the tensile strength of the material, this is not the case for I and similar sections used in construction.

ELASTIC LIMIT OF BEAMS.

If we define the elastic limit as the point at which the stress ceases to be proportional to the strain, it is evident that, according to the theory presented, the elastic limit would be the same for a bending stress as for tension and compression; also that this theory and the common theory would be identical below this limit. It is needless to refer to cast iron in this connection, as it has no elastic limit as defined above. The table of results of Bauschinger's experiments on rectangular steel bars, gives higher values for the elastic limit as determined by transverse tests than as determined by tension tests. There are good reasons why this may be expected. The values of the elastic limit of a material, as determined by tension and bending tests, are distinct quantities. We do not know that, when the point is reached in a beam test at which the observed deflection ceases to be proportional to the load, or at which the first perceptible permanent set occurs, the condition of the most strained fibre is the same as at the point called the elastic limit in a tension or compression test. In a beam loaded at the middle the extreme fibres at the section under the load are strained the most. It is not possible to detect any lack of perfect elasticity until these fibres have been actually strained beyond their elastic limit; the amount of the excess varying with the precision of the deflection measurements and with the form of cross-section and dimensions of the beam. If permanent sets are employed to determine the elastic limit, M. Considère, in his memoir already referred to, calls attention to another cause of difference; namely, that when the extreme fibres are strained beyond the elastic limit and the load removed, the fibres near the neutral axis, which have not yet reached the elastic limit, tend to return to their original length; while the extreme fibres tend to retain a certain permanent set. The result is that the extreme fibres on the tension side are subjected to a compressive stress, and those on the compression side to a tensile stress; consequently the actual permanent deflection is less than would be the case if the extreme fibres were left free to retain their total permanent set, as in case of a direct tension or compression test. From these considerations it seems reasonable to conclude that the difference observed by Bauschinger and other experimenters between the elastic limit, as determined by tension and bending, does not discredit the theory here examined.

It was the aim of the writer to make the examination of each of the beams tested as thorough as possible. While a greater number of experiments would seem necessary in order to fully test the theory, it is hoped that those presented in this paper will be found of real value in this line of investigation.

TABLE I. — CAST-IRON BEAM NO. 1.

Width = 1.003 in. Depth = 3.008 in. Span = 30.5 in. Distance between central knife edges = 6.5 in.

Loads.	Dist. of neutral axis from comp. side in terms of depth.		Bending Moment.		$M=\frac{f}{y}I.$	Maximum Fibre Stress from Diagrams.		$f=\frac{M}{I}y.$
	Diagram.	Experiment.	Diagram.	Experiment.		Tension.	Compression.	
lbs.			in. lbs.	in. lbs.	in. lbs.	lbs. per sq. in.	lbs. per sq. in.	lbs. per sq. in.
100	...	...	...	...	...	...	...	...
1100	.525	.446	6470.	6600.	7563.	5000.	3200.	4360.
2100	.512	.440	12740.	12600.	12710.	8400.	7100.	8330.
3100	.491	.438	18610.	18600.	16790.	11100.	10800.	12300.
4100	.478	.442	23890.	24600.	19970.	13200.	15000.	16260.
5100	.462	.432	29350.	30600.	23290.	15400.	19400.	20230.
6100	.446	.426	35230.	36600.	25860.	17100.	24200.	24200.
7100	.432	.431	40360.	42600.	27830.	18400.	28800.	28160.
7600	.423	.421	43640.	45600.	29190.	19300.	31400.	30150.
8100	.415	.410	46550.	48600.	30400.	20100.	33600.	32130.
†8770	...	...	*50450.	52620.	*32020.	*21170.	*36550.	34790.

† Breaking load, fracture sound.

* Estimated. The tensile strength of the specimen cut from the tension side of this beam was 20,780 lbs. per sq. in.

TABLE II. — CAST-IRON BEAM No. 2.

Width = 1.006 in. Depth = 3.009 in. Span = 30.5 in. Distance between central knife edges = 6.5 in.

Loads.	Dist. of neutral axis from comp. side in terms of depth.		Bending Moment.		$M=\frac{f}{y}I.$	Maximum Fibre Stress from Diagrams.		$f=\frac{M}{I}y.$
	Diagram.	Experiment.	Diagram.	Experiment.		Tension.	Compression.	
lbs.			in. lbs.	in. lbs.	in. lbs.	lbs. per sq. in.	lbs. per sq. in.	lbs. per sq. in.
100	...	...	...	...	...	...	...	...
600	.500	.625	3460.	3600.	2280.	1500.	2100.	2360.
1100	.515	.563	5870.	6600.	5010.	3300.	4000.	4340.
1600	.500	.520	9030.	9600.	8050.	5300.	6200.	6320.
2100	.494	.500	11470.	12600.	10020.	6600.	7800.	8290.
2600	.483	.482	14270.	15600.	12300.	8100.	9800.	10270.
3100	.475	.481	17140.	18600.	14270.	9400.	12100.	12250.
3600	.466	.473	20500.	21600.	16020.	10550.	14400.	14220.
4100	.459	.465	23020.	24600.	17910.	11800.	16600.	16200.
4600	.451	.454	25870.	27600.	19580.	12900.	18800.	18180.
5100	.442	.444	28940.	30600.	21250.	14000.	21200.	20150.
5600	.434	.439	31900.	33600.	22540.	14850.	23600.	22130.
6100	.427	.431	34760.	36600.	23990.	15800.	26000.	24110.
6600	.419	.422	37830.	39600.	25500.	16800.	28400.	26080.
7100	.411	.418	40520.	42600.	26340.	17350.	30700.	28060.
7600	.403	.408	43440.	45600.	27400.	18050.	33000.	30040.
†8330	...	...	*47700.	49980.	*28950.	*19070.	*36360.	32930.

† Breaking load, fracture sound.

* Estimated. The tensile strength of the specimen cut from the tension side of the beam was 18,974 lbs. per sq. in.

TABLE III. — CAST-IRON BEAM No. 3.

⊥ section. Total depth = 3.004 in. Thickness of web = 1.009 in. Thickness of flange = 1.004 in. Width of flange = 3.005 in. Span = 32.5 in.
Centre of gravity of cross-section is .632 depth from the top of web. Tested with the flange on the tension side.

Loads.	Dist. of neutral axis from comp. side in terms of depth.		Bending Moment.		$M=\frac{f}{y}I.$	Maximum Fibre Stress from Diagrams.		$f=\frac{M}{I}y.$	
	Diagram.	Experiment.	Diagram.	Experiment.		Tension.	Compression.	Tension.	Compression.
lbs.			in. lbs.	in. lbs.	in. lbs.	lbs. per sq. in.	lbs. per sq. in.	lbs. per sq. in.	lbs. per sq. in.
1000	.683	.638	5080.	6500.	7280.	2200.	2000.	1963.	3380.
2000	.682	.636	10696.	13000.	13240.	4000.	4800.	3920.	6760.
3000	.684	.624	17530.	19500.	19030.	5750.	8600.	5890.	10140.
4000	.662	.615	24321.	26000.	23830.	7200.	11900.	7854.	13520.
5000	.649	.616	30465.	32500.	27800.	8400.	15400.	9818.	16900.
6000	.636	.595	37034.	39000.	32770.	9900.	18600.	11782.	20280.
7000	.625	.586	43658.	45500.	37070.	11200.	22300.	13750.	23660.
8000	.615	.583	50392.	52000.	40710.	12300.	25600.	15710.	27040.
9000	.605	.574	57274.	58500.	44350.	13400.	28800.	17670.	30420.
10000	.595	.570	63948.	65000.	47660.	14400.	31900.	19640.	33800.
11000	.586	.565	71056.	71500.	51140.	15450.	34900.	21602.	37180.
12000	.578	.556	77935.	78000.	54440.	16450.	37750.	23566.	40557.
† 12500	...	...	*81375.	81250.	*56100.	*16950.	*39100.	24548.	42247.

† Approximate breaking load, fracture sound. * Estimated. Average tensile strength of specimens cut from the flange was 18,050 lbs. per sq. in.

TABLE IV. — WROUGHT-IRON BEAM.

Width = 1.009 in. Depth = 3.07 in. Span = 36 in. Distance between centre bearing points = 4 in.

[NOTE. — In this test, which was the first made, cylinders were used in place of the centre knife edges. They were afterwards abandoned as unsatisfactory.]

Loads.	Dist. of neutral axis from comp. side in terms of depth.		Bending Moment.		$M=\frac{f}{y}I.$	Maximum Fibre Stress from Diagrams.		$f=\frac{M}{I}y.$
	Diagram.	Experiment.	Diagram.	Experiment.		Tension.	Compression.	
lbs.			in. lbs.	in. lbs.	in. lbs.	lbs. per sq. in.	lbs. per sq. in.	lbs. per sq. in.
2000	Practically coincides with the centre of gravity of the cross-section.	.455	17340.	16000.	18640.	11760.	8500.	10086.
4000		.500	31910.	32000.	31780.	20050.	20010.	20182.
6000		.485	44260.	48000.	44320.	27960.	27740.	30278.
8000		.494	64480.	64000.	48340.	30500.	31750.	40374.
9000		.491	69480.	72000.	50720.	32000.	32700.	45422.
10000		.497	70560.	80000.	51510.	32500.	34500.	50470.
11000		.504	79340.	88000.	54360.	34300.	37500.	55518.
12000	.494	.494	89320.	96000.	59200.	37350.	43750.	60566.
12500	.488	.491	92980.	100000.	61180.	38600.	46500.	63090.
13000	.485	.489	97500.	104000.	63080.	39800.	49500.	65614.
13500	.479	.484	101800.	108000.	64590.	40750.	52600.	68138.
14000	.470	.477	106770.	112000.	66880.	42200.	56000.	70662.
14500	.466	.470	110250.	116000.	68870.	43450.	58200.	73186.
15000	.460	.461	114870.	120000.	71240.	44950.	60750.	75710.
15500	.455	.455	118980.	124000.	73860.	46600.	62900.	78234.
16000	.451	.447	123400.	128000.	76470.	48250.	65350.	80758.
16500	...	.440	...	132000.	...	...	...	83282.
17000	...	.438	...	136000.	...	...	...	85806.
17500	...	.435	...	140000.	...	...	...	88330.

Test discontinued on account of the excessive deflection of the beam.

Table V. — Bessemer Steel Beam.

Width = 1.048 in. Depth = 3.00 in. Span = 36.5 in. Distance between centre knife edges = 6.5 in.

Loads.	Dist. of neutral axis from comp. side, in terms of depth.		Bending Moment.		$M=\frac{f}{y}I.$	Maximum Fibre Stress from Diagrams.		$f=\frac{M}{I}y.$
	Diagram.	Experiment.	Diagram.	Experiment.		Tension.	Compression.	
lbs.			in. lbs.	in. lbs.	in. lbs.	lbs. per sq. in.	lbs. per sq. in.	lbs. per sq. in.
500	...	...	...	...	...	...	...	...
4500	.500	.508	35370.	33750.	34980.	22250.	22750.	21470.
8500	.496	.510	66100.	63750.	60910.	38750.	43000.	40560.
10500	.497	.518	78000.	78750.	70350.	44750.	46000.	50098.
12500	.499	.511	90220.	93750.	73730.	46900.	46000.	59640.
14500	.503	.505	104600.	108750.	74670.	47500.	46900.	69182.
16500	.491	.491	128760.	123750.	94000.	59800.	63250.	78724.
18500	.486	.487	142350.	138750.	105320.	67000.	73000.	88266.
20500	.483	.484	157960.	153750.	114120.	72600.	81000.	97808.
22500	...	.480	...	168750.	121200.	77100.	...	107350.

Test discontinued on account of the excessive deflection of the beam.

Plate II.

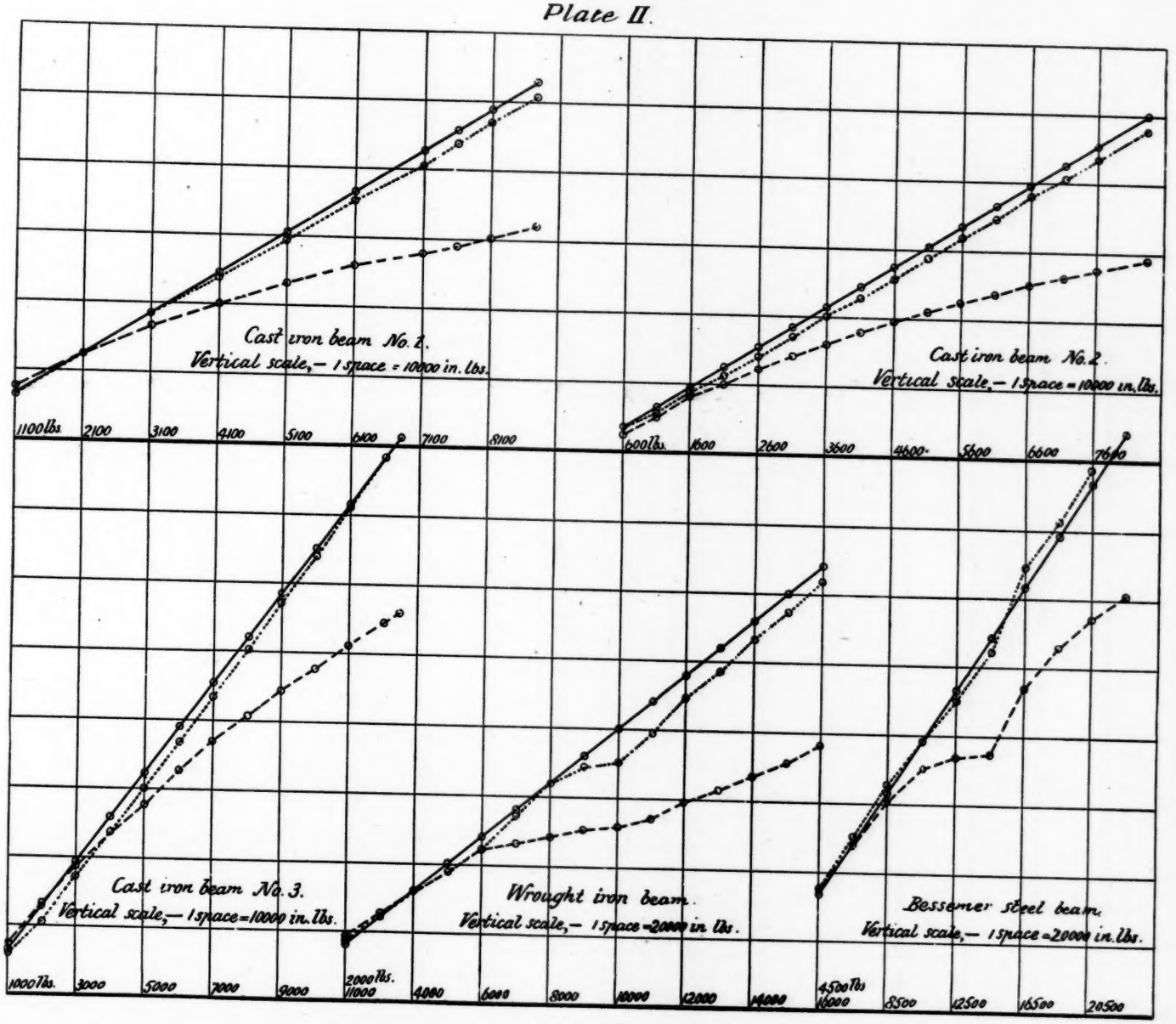
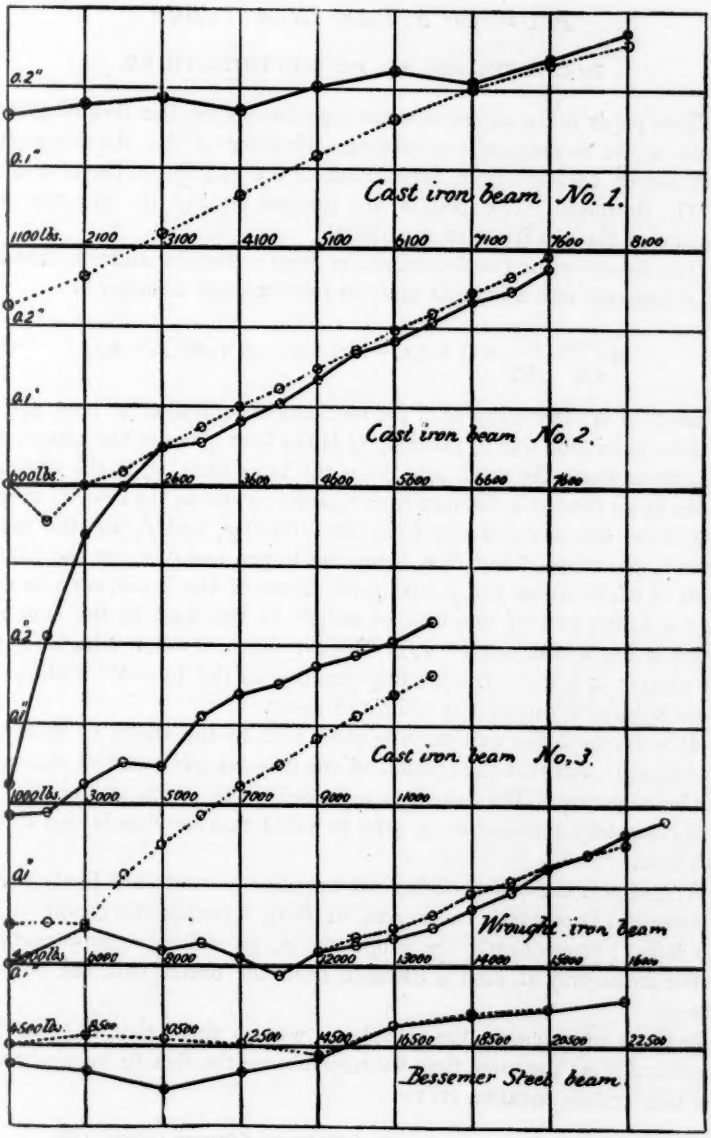

Cast iron beam No. 2.
Vertical scale,— 1 space = 10000 in. lbs.
1100 lbs. 2100 3100 4100 5100 6100 7100 8100
Cast iron beam No. 2.
Vertical scale,— 1 space = 10000 in. lbs.
600 lbs. 1600 2600 3600 4600 5600 6600 7600
Cast iron beam No. 3.
Vertical scale,— 1 space = 10000 in. lbs.
1000 lbs. 3000 5000 7000 9000
Wrought iron beam.
Vertical scale,— 1 space = 20000 in. lbs.
2000 lbs. 11000 4000 6000 8000 10000 12000 14000
Bessemer steel beam.
Vertical scale,— 1 space = 20000 in. lbs.
4500 lbs 16000 8500 12500 16500 20500

Plate I.


0.2"
0.1"
Cast iron beam No. 1.
1100 lbs.
2100
3100
4100
5100
6100
7100
7600
8100
0.2"
0.1"
Cast iron beam No. 2.
1000 lbs.
2600
3600
4600
5600
6600
7600
Cast iron beam No. 3.
1000 lbs.
3000
5000
7000
9000
11000
Wrought iron beam
6000
8000
12000
13000
14000
15000
16000
6500 lbs.
8500
10500
12500
14500
16500
18500
20500
22500
Bessemer Steel beam

*FLOW OF STEAM IN A TUBE.**

By C. H. PEABODY, S.B., and B. G. BUTTOLPH, S.B.

This paper is the record of some experiments on the flow of steam made in the mechanical engineering laboratory of the Massachusetts Institute of Technology in preparation of the graduation thesis of Mr. B. G. Buttolph. The results are deemed worthy of attention on account of the paucity of such material.

The equation for the flow of steam from a straight uniform tube of large diameter into a straight uniform tube of small diameter is

$$A\left(\frac{w_b}{2g}-\frac{w_a}{2g}\right)=Q+x_a r_a-x_b r_b+q_a-q_b+A\sigma(p_a-p_b), \qquad (1)$$

in which A is the reciprocal of the mechanical equivalent of heat, and g is the acceleration due to gravity; Q is the heat given to the stream at the orifice where the small tube joins the large one; w_a is the velocity in the large tube at a distance from the orifice, and w_b the velocity in the small tube also at a distance from the orifice; p_a and p_b are the pressures in the tubes A and B, p_a being the larger, and r_a, r_b are the latent heats of vaporization, and q_a and q_b the heats of the liquid, corresponding; x_a is the part of one unit of weight of the fluid in the tube A, which is dry steam, and $1-x_a$ is the part which is water mingled with the steam; x_b is the corresponding quantity for the tube B. Finally, σ is the volume of one unit of weight of water.

It is assumed that neither tube gives heat to the steam or receives heat from it, and that the friction of the fluid on the sides of the wall can be neglected. The heat Q is supposed to be given at the orifice. It is commonly assumed to be zero, in which case the flow is said to be adiabatic.

At and near the orifice eddies and irregular currents are likely to be of sufficient importance to prevent us from knowing the condition of the steam; consequently the properties p_a, p_b, and x_a, x_b must pertain to the steam only at such a distance from the orifice that the flow is steady.

In these experiments the velocity w_a was so small that it could be neglected. At the same time we may assume the flow to be adiabatic, and thus reduce equation (1) to

* Read before the American Society of Mechanical Engineers, October, 1888.

$$A\frac{w_b}{2g} = x_a r_a - x_b r_b + q_a - q_b + A\sigma(p_a - p_b). \qquad (2)$$

The value of x_a must be determined by experiment. x_b can then be determined by the equation

$$\frac{x_a r_a}{T_a} + \int_{t_o}^{t_a} \frac{cdt}{T} = \frac{x_b r_b}{T_b} + \int_{t_o}^{t_b} \frac{cdt}{T}, \qquad (3)$$

which applies to any adiabatic change of a mixture of a liquid with its vapor. In this last equation, T_a is the absolute temperature of the steam in the tube A, and T_b that of the stream in the tube B. c is the specific heat of water, and $\int \frac{cdt}{T}$ is the entropy of the liquid above that at freezing point.

If the area of the cross-section of the tube be N, then the volume per second is

$$V = Nw_b,$$

and the weight per second G is obtained by dividing by the specific volume

$$v_b = x_b u_b + \sigma,$$

in which u_b is the increase in volume of one unit of weight of water when it is entirely vaporized. Therefore

$$G = \frac{Nw_b}{x_b u_b + \sigma}. \qquad (4)$$

The tube used in these experiments was of brass, 0.275 of an inch internal diameter and eight inches long. At the entrance end a plate 1½ inches in diameter was driven on flush with the end of the tube, and the orifice was well rounded to avoid contraction. This tube was the tube B, and led from an iron pipe six inches in diameter and two feet long, which formed a chamber in which the steam came to rest, and from which it was led to a surface condenser.

The two pieces of six-inch pipe were capped on the outer ends, and had flanges on the inner ends, between which was a plate holding the experimental tube. The whole apparatus was lagged on the outside, and the plate holding the brass tube was covered on both sides with about four inches of asbestos to prevent the flow of heat from one part of the apparatus to the other.

Steam was led to the apparatus by a lagged pipe one inch in diameter, and away from it to the condenser by a pipe of the same size. Each of these pipes had a valve near the apparatus. The valve in the supply

pipe was used merely to shut off the steam when the apparatus was not in use, and during an experiment it was wide open, so that the pressure in the tube *A* was full boiler pressure, or nearly so. The valve in the exhaust pipe was manipulated to maintain the desired difference of pressure between the two parts of the apparatus. Each chamber of the apparatus was supplied with a good steam gauge, and with a thermometer in a long brass cup filled with oil. The gauges were compared with a mercury column in the laboratory, and the thermometers were calibrated, and their freezing and boiling points were determined. The exhaust steam was condensed in a small surface condenser and weighed in a tank.

The experiments were begun after the apparatus had been running steadily for some time, and lasted about half an hour.

Steam for the experiments was drawn from the main steam pipe, and as the supply pipe had a drip near the apparatus which remained open during an experiment, it was assumed that the quality of the steam was the same as that in the main pipe. A large number of experiments with different types of calorimeters gave 1½ to 2 per cent of moisture in the steam. Later experiments with a new type of calorimeter, described in a paper presented to this meeting, gave under normal conditions 1 to 1.5 per cent of moisture. With a large difference of pressure the steam after coming to rest in the chamber beyond the tube, was superheated, and by the method employed with the new calorimeter the amount of moisture could be calculated, giving the same result.

	Pressure of Steam in front of Tube.	Pressure of Steam beyond Tube.	Difference of Pressure.	Flow of Steam per Hour by Tank in Pounds. G_t	Flow of Steam per Hour, Calculated in Pounds. G_c	$\frac{G_t}{G_c}$
1	69.1	4.4	64.7	229.0	182.3	1.260
2	69.6	9.7	59.9	230.4	211.2	1.091
3	71.3	14.8	56.6	242.0	233.4	1.037
4	69.1	19.4	49.7	232.0	242.2	0.958
5	70.0	24.5	46.5	234.5	256.6	0.914
6	70.3	29.1	41.2	229.0	261.5	0.876
7	72.0	34.2	37.8	232.0	268.9	0.860
8	72.0	39.5	32.5	221.4	266.9	0.830
9	71.6	44.2	27.4	216.5	260.1	0.833

As the more recent data were not available till the work was nearly complete, the moisture was assumed to be 2 per cent in all the calculations. The error from this source is inconsiderable.

The data and results of the experiments are given in the following table, and are plotted in the accompanying diagram (Fig. 10). The abscissæ are differences of pressures, and the ordinates the ratio of the actual flow to the calculated flow. The curve on the diagram is intended merely to show the degree of regularity of the experiments more readily.

The table will be readily understood from the headings. It should, however, be noted that the calculated flow per hour is 3600 times that given by equation (4).

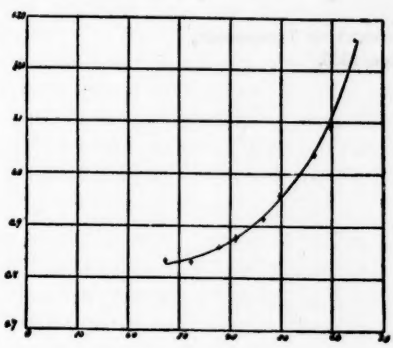


FIG. 10.

The ratio of the actual quantity to the calculated quantity, if the theory were entirely applicable to this case, should resemble the coefficient of flow for water through a short pipe, and should not be greater than unity. The marked, though regular, increase of this ratio with the increase of the difference of pressure, and the fact that, for the larger differences, this ratio is larger than one, shows conclusively that some of the assumptions are inadmissible.

It is not improbable that heat is given by the steam to the tube at the admission end, and regained by the steam towards the exit end. Such an interchange must influence both the condition of the steam at orifice and the rate of flow. The well-known phenomena of cylinder condensation and reëvaporation in steam engines show that such an action may be energetic. It is also possible that the length of the tube is not sufficient to ensure a steady flow.

It is noticeable that the weight of steam discharged by the tube has a maximum, which is for a difference of pressure of about 35 pounds by the equation, and for a difference of pressure of about 55 pounds by experiment.

Some earlier experiments of this year are not recorded, on account of discrepancies due to the imperfection of the methods, and for the same reason experiments of two preceding years are excluded.

In such a series of experiments the superior pressure should be the same for all of the experiments. Some of the irregularity of the results may be chargeable to the fact that the boiler pressure was not the same on different days.

In closing, it should be stated that all the work of experiment and calculation was done by Mr. Buttolph.

Massachusetts Institute of Technology,
October, 1888.

*A SIMPLE CALORIMETER.**

By C. H. PEABODY, S.B.

A CALORIMETER for determining the quality of moist steam has been devised by the writer, which depends on the property that dry steam is superheated by wire drawing, and which appears to have valuable features.

The first calorimeter of this type, made and used in the laboratory of the Massachusetts Institute of Technology, was made as follows: A piece of pipe six inches in diameter and ten inches long was capped at each end. Into the upper end was fitted a half-inch pipe, bringing the steam to be tested, a thermometer cup, and a steam gauge. From the lower cap an inch pipe led away the exhaust steam. The supply pipe brought steam from the main steam pipe nearly over head. Near the calorimeter was a T which formed a pocket, with a drip at the lower opening, and a branch from the side opening leading to an angle valve in the upper cap of the condenser. The pipe further was well wrapped with hair felt, and it was assumed that the steam had the same quality as in the main pipe. The calorimeter itself was wrapped in asbestos board and hair felt, and covered with Russia iron.

Two other calorimeters have been made which differed from the first only in size. One is made of a piece of two-inch pipe eight inches long, and the other of a piece of four-inch pipe of the same length. The only difference in the action of these three calorimeters appears to be that the smaller ones are more sensitive, *i.e.*, they respond more quickly to any change of condition.

To make an experiment, the valve in the supply pipe is opened a slight amount, about one-eighth of a turn, and a valve in the exhaust pipe is regulated to give a suitable pressure in the calorimeter. After the gauge and thermometer attached become steady, their readings are taken together with the reading of the boiler gauge.

If p is the boiler pressure, then r is the heat of vaporization, and q the heat of the liquid corresponding, and x may represent the dry steam in one pound of the mixture drawn from the main steam pipe, so that $1-x$ is the water or priming. The heat in one pound of the mixture is $xr+q$.

* Read before the American Society of Mechanical Engineers, October, 1888.

Let p_1 be the pressure in the calorimeter, and λ_1 the total heat, and t_1 the temperature corresponding. Let t_s be the temperature of the superheated steam by thermometer. Then the heat in one pound of steam in the calorimeter is

$$\lambda_1 + c_p\,(t_s - t_1),$$

in which c_p is the specific heat of the superheated steam at constant pressure (0.4808).

Assuming that no heat is lost,

$$xr + q = \lambda_1 + c_p\,(t_s - t_1)\,; \tag{1}$$

$$\therefore\ x = \frac{\lambda_1 + c_p\,(t_s - t_1) - q}{r}\,; \tag{2}$$

and the priming is

$$1 - x. \tag{3}$$

The following experiments were made on the first or 6″ calorimeter. The boilers were forced during the test to supply an unusual draught of steam for heating and other purposes, and the pressure was less than the usual pressure in the main steam pipe, and fluctuated during the test.

Table I. — Tests on the 6″ Calorimeter.

Gauge Pressure.		Temperature in the Calorimeter F.	Priming.
Boiler.	Calorimeter.		
71.2	38.5	286.7	0.011
60.3	26.8	271.8	0.012
63.0	17.5	264.9	0.013
60.6	7.0	258.8	0.011
69.0	3.7	258.1	0.012

After the smaller calorimeters were completed, all three were set up and compared. In Table II. the several groups of two and three experiments were made simultaneously.

TABLE II.

Barometer 14.8 pounds.

Size of Calorimeter.	Gauge Pressure.		Temperature in the Calorimeter F.	Priming.
	Boiler.	Calorimeter.		
2″	71.3	37.5	288.1	0.01
4″	71.3	38.3	288.9	0.01
6″	57.0	9.5	246.2	0.018
4″	57.0	8.4	245.8	0.018
2″	57.0	7.3	242.6	0.019
4″	60.8	4.7	246.6	0.017
2″	60.8	4.7	244.0	0.018
4″	71.2	6.2	248.4	0.02
2″	71.2	6.5	248.4	0.02
4″	73.0	6.6	251.2	0.02
2″	73.0	6.9	250.5	0.02
4″	74.5	6.8	252.5	0.019
2″	74.5	7.0	251.6	0.019
4″	75.5	6.2	253.4	0.018
2″	75.5	6.7	252.0	0.018
6″	69.8	12.0	268.2	0.012
6″	69.8	5.0	253.4	0.016

A comparison of the several groups shows that all of the calorimeters give substantially the same results.

A little consideration shows that this type of calorimeter can be used only when the priming is not excessive, otherwise the wire drawing will fail to superheat the steam, and in such case nothing can be told about the condition of the steam, either before or after wire drawing. To find

this limit for any pressure t_s may be made equal to t_1, in equation (2); that is, we may assume that the steam is just dry and saturated at that limit in the calorimeter. Ordinarily the lowest convenient pressure in the calorimeter is the pressure of the atmosphere, or 14.7 pounds to the square inch. Table III. has been calculated for several pressures in the manner indicated. It shows that the limit is higher for higher pressures, but that the calorimeter can be applied only when the priming is moderate.

TABLE III.

Pressure.		Priming.
Absolute.	Gauge.	
300	285.3	0.077
250	235.3	0.070
200	185.3	0.061
175	160.3	0.058
150	135.3	0.052
125	110.3	0.046
100	85.3	0.040
75	60.3	0.032
50	35.3	0.023

When this calorimeter is used to test steam supplied to a condensing engine, the limit may be extended by connecting the exhaust to the condenser. For example, the limit at 100 pounds absolute, with 3 pounds absolute in the calorimeter is 0.064 instead of 0.046 with atmospheric pressure in the calorimeter.

In case the calorimeter is used near its limit, that is, when the superheating is a few degrees only, it is essential that the thermometer should be entirely reliable, otherwise it might happen that the thermometer would show superheating when the steam in the calorimeter was saturated or moist. In any other case a considerable error in the temperature would produce an inconsiderable effect on the result. Thus, at 100 pounds absolute with atmospheric pressure in the calorimeter, 10° F. of superheating indicates 0.035 priming, and 15° F. indicates 0.032 priming. So also a slight error in the gauge reading has little effect. Suppose the reading to be apparently 100.5 pounds absolute instead of 100, then

with 10° of superheating the priming appears to be 0.033 instead of 0.032. It is, however, to be remarked that no gauge is to be trusted for such work unless it has been compared with a correct mercury column.

It is of interest to compare this calorimeter with the Barrus superheated steam calorimeter,* more especially as that calorimeter can be most advantageously applied with steam of moderate or low pressure, at which the new calorimeter has a narrow limit. It is scarcely necessary to recall the fact that in the Barrus calorimeter the steam to be tested is dried and superheated in an instrument resembling a surface condenser, by a stream of highly superheated steam. To show the difference between the two types of calorimeter, the following table has been calculated on the assumption that the superheated steam has an initial temperature of 500°, and a final temperature of 10° above the temperature of saturated steam of the given pressure, while the moist steam is supposed to be dried and superheated 5°. It will be seen that the limit under these conditions is widest for lowest pressures, and that it is narrower at high pressures than that of the new type. While the limit is determined by arbitrarily assumed conditions, it is believed that it will be found narrower rather than wider in practice.

TABLE IV. — BARRUS SUPERHEATED STEAM CALORIMETER.

Pressure.		Priming.
Absolute.	Gauge.	
50	35.3	0.170
75	60.3	0.095
100	185.3	0.086
125	110.3	0.078
150	135.3	0.071
175	160.3	0.065
200	185.3	0.059
250	235.3	0.049
300	285.3	0.040

* Trans. A. S. M. E., Vol. VII. p. 178, and Vol. VIII. p. 235.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
October, 1888.

*HEATING CARS BY STEAM FROM THE LOCOMOTIVE.**

By GAETANO LANZA, S.B., C. and M.E.

To the Railroad Commissioners of the State of Massachusetts:

Gentlemen:— In accordance with your directions I have made an investigation of the methods in use by such of the railroads in the State of Massachusetts as heat their cars by means of steam taken from the locomotive, and also of those in use by the Atchison, Topeka, & Sante Fe, and I would respectfully present the following report:—

There is, of course, as in any new and important departure, a large number of devices proposed by this, that and the other individual whose chief object is to produce a system on which he can obtain a patent, and then to get the system adopted as a whole by as many roads as possible, so that he may derive the most profit possible from his patent rights.

While the railroad companies in this State are nominally using, as a rule, some one or more of the so-called systems, they have in many cases been trying the different appliances, more or less regardless of the systems, and the subject will be treated in this report from the latter point of view, the different methods for accomplishing any one special object being discussed together, and not as forming a part of a certain so-called system.

We may, therefore, classify the subjects to be considered as follows:—

1. The Means of coupling the Steam Pipes of the Cars together.
2. The Means of reducing the Locomotive Pressure before it reaches the Train.
3. The Means of disposing of the Condensation.
4. The proper Piping in the Cars to give the Necessary Radiating Surface, and Freedom of Circulation.
5. The Proper Valves to be used.
6. The Disposition of the Main Steam Pipe.
7. The Use of Live Steam, Exhaust Steam, or Water.
8. Auxiliary Boilers under the Cars.

* Report to the Railroad Commissioners of the State of Massachusetts, June, 1888.

9. Means of regulating the Heat in Moderate Weather.
10. Means of taking Care of Cars when stored away.
11. Individual Heaters.
12. Tests to determine the Amount of Steam used.
13. Experience of the Roads.
14. General Remarks.

COUPLINGS.

There is a large number of steam couplings in the market, each so-called system having a different one. Indeed, it might be said that the differences in the couplings form one of the most distinctive features of the systems. No detailed description of them is necessary, but the following distinguishing features should be mentioned:—

While the greater part depend for flexibility on a flexible rubber hose, there are some which claim as a specially good feature that they are made entirely of metal. Such couplings depend for their flexibility upon ball joints and slip joints. Experience has shown that they wear out and leak badly in a very short time, so that this class of couplings may be pronounced unsuitable.

A feature which exists in a number of couplings and is undoubtedly good is the property of automatically uncoupling whenever the cars break apart. This feature is enjoyed by the Sewall, the Westinghouse, and some other couplings. In this class, also, each part of the coupling is attached to a piece of hose attached to the main train pipe of each car, and these couplings should be, and generally are, interchangeable, each half being like the other half. The tightness in such couplings is insured by the force of gravity causing the rubber gaskets, which should be of hard rubber or some similar composition, to press against each other. Such couplings need a certain length of hose, and, of course, form a pocket between the cars which might be supposed to collect condensation water, but which, as far as observed, does not present this difficulty.

Some couplings consist of one piece of hose intermediate between two metallic portions to which it is permanently attached, so that this entire portion can be taken off without making up any joints. These couplings have either metallic surfaces in contact, or else rubber gaskets, and are usually made tight by means of a screw. If the train were to break apart, they would not uncouple, but would have to break. Moreover, it does not seem probable that a metallic joint can be kept as tight as a gasket, unless it be more carefully handled than it is likely to be in the regular service of a railroad.

In conclusion, it is very important that all those roads that are at all likely to interchange cars should adopt the same coupling, even though they have nothing else alike.

The following considerations favor the adoption of the Westinghouse air-brake coupling: —

The train hands are all familiar with its management.

The patent expires shortly, and the payment of royalty would be avoided.

The three-quarter inch coupling, now used for the air brake, would doubtless be too small, and it would be necessary to adopt the one and one-half inch coupling. Also, it would be necessary to have the gaskets made of hard rubber or of some similar compound and not of soft rubber. The Boston & Albany and the New York & New England railroads have already tried the Westinghouse couplings, and they work well.

REDUCING VALVES.

In regard to the means for reducing the pressure of the steam before it reaches the train, the most primitive way is to introduce, into the pipe leading to the train, an ordinary globe valve and to require the engineer to regulate it by hand so as to produce the proper pressure on the train. Some do this from choice, and others because they have been unable to find a reducing valve that did not get out of order. Some of those who use a globe valve add a safety valve, which blows off at a certain pressure, and thus warns the engineer that the globe valve wants attention. Nevertheless, the proper way to accomplish the object is to introduce into the pipe a reducing valve, which, when once set, will keep the pressure on the train uniform without the necessity of constant adjustment by the engineer.

There are many reducing valves in the market, but when they are subjected to high pressures and not handled with more than ordinary care, they too often fail. This failure is often due to their extreme delicacy and to the difficulty in keeping lubricated certain parts which are exposed to very high temperatures and require specially good lubrication. These valves generally have some kind of flexible diaphragm, and the possibility of making such a valve succeed, under trying circumstances and long usage, is questionable. On the other hand, valves composed of pistons of different sizes have been tried, but not to any great extent, and the most that can be said is that there is promise of success in this quarter.

TRAPS.

The means of disposing of the condensation without letting it freeze, and thus burst the pipes or other connections, is one of the most serious questions of all those connected with steam heating. Even the so-called frost-proof traps freeze up at times.

First as to the object of any trap.

In some of the so-called systems the steam is taken into each car from a cross or a T in the main steam pipe under or in the floor of the car, and that portion which condenses in any one car must be drained from that car, and does not pass into the next. Of course this draining can be accomplished by means of a simple globe valve without any trap at all; but if this is done, the following difficulties are met: —

If the valve is closed while the train is running, too much condensation water may collect before it can be let out, thus getting water into the main pipe, and preventing a good circulation of the steam and, at the same time, permitting the condensation to cool in the lower part of the pipe, and perhaps even freeze and burst the pipe. If, on the other hand, the globe valve is left open enough to avoid the above-described dangers, there is leakage and consequent waste of steam, and this may amount to a good deal, especially when the jarring of the train causes the globe valve to open wider during the run. These objections become serious on through trains, and in all cases where the times between stations are long and the stops short, and where the management of the valves is intrusted to green hands; but on roads where the times between stations are short, and where the work is only intrusted to well-drilled hands, the objections stated above are not valid. Thus on the Connecticut River road and on the Boston, Revere Beach & Lynn there is no trouble of this sort, and traps could easily be dispensed with. Indeed, there is never any difficulty with frozen traps in the case of roads where the cars are kept warm all the time, whether running or standing still, but there is difficulty when cars have to be left for long periods in the cold with no heat supply. By the Martin, the Emerson, and several other systems, each car is drained separately.

In the Sewall system the steam passes from the main pipe into a valve in the middle of the car. If this valve is wide open, the whole, and if partly open, a part, of the steam passes through the car back to the main pipe, from which the condensation may be drained off by a trap or by the globe valve if it is open wide enough. If the trap or valve is closed, the whole of the condensation is forced back into the rear car, and from the end of the main pipe of the rear car it is blown

out. This is the method most commonly used on the Old Colony and the Fitchburg railroads during the run, both of these roads using the new style Sewall valve. If the valve or trap is partially open, a part is disposed of in each way. When the old style valve is used, they are more likely to depend upon the trap to drain the entire condensation of the car. When the condensation is all forced back and globe valves are used instead of traps, it is customary to make use of the valves only on two occasions : —

(*a*) On heating up, to drain the condensation when the steam first starts through the car.

(*b*) On putting the cars away, to drain the main pipe thoroughly, so as to avoid all danger of freezing. For these purposes the globe valve works much better than the trap, as the latter does not furnish a sufficiently free exit for the steam, and freezing ensues when the cars are exposed without heat. There is an increasing tendency with those who use the Sewall system to discard the Sewall trap and use a plain globe valve. This is done on the Fitchburg and on the Old Colony roads.

The idea at the basis of most of the traps, whether those used to drain the main pipe or the car, is that the contraction and the expansion of some expansible metal or liquid, due to different degrees of temperature, shall respectively open and close the valve, — thus opening to let out the water, but closing to keep in the steam. This is effected by causing the trap to close at a certain fixed temperature which, if the steam in the car were at atmospheric pressure, would be 212 degrees Fahrenheit.

The operation of the trap is supposed to be as follows : While the pipes are full of steam, so that the expansible metal is exposed to the temperature of the steam, it expands, closing the valve, and the trap is closed ; but when the steam condenses, so that a certain amount of condensation water collects in the bottom of the pipes, this water comes in contact with the expansible metal. As this water at first is practically at the temperature of the steam, the trap does not open immediately ; but when the water nearest the trap cools down, the expansible metal contracts, the valve opens, and the water escapes. As soon as steam replaces the water, the metal is supposed to expand again and close the valve. The principal difficulty with these traps seems to be that, when the cars are set off in a cool place, they either do not act promptly enough, or else the little slow drip freezes on its way out, and the passages being narrow, the trap gets frozen up, and also the pipes, and hence the steam, when let on again, does not get through. An attempt has been made to remedy this difficulty by means of the so-called frost-

proof traps, which have an opening at the top as well as at the bottom, so that even if the lower orifice is frozen, the upper one will furnish an outlet for the steam when it first comes in, until the lower one is thawed out and performs its functions properly. These traps have succeeded, on the whole, rather better than the others, but they can hardly yet be pronounced a success.

The various traps in use may be classified as follows: —

(*a*) A species of box trap, such as the Sewall or the Curtis.

(*b*) A species of trap known as a thermostatic trap, which may be illustrated by the Martin or by a trap devised and used by Mr. Henney, superintendent of motive power of the New York & New England Railroad.

Both kinds have similar troubles and at times freeze up.

There is another way of taking care of the water of condensation, which, though it has not yet had an extensive trial, seems to afford the means of avoiding frozen traps. It is the method adopted by Mr. George A. Houston of the Atchison, Topeka & Santa Fe Railroad. The method which he has been using the past winter consists in having under the car a tank into which the condensation falls, and from near the bottom of this tank proceeds a small pipe running up into the car, and emptying at the top into a tank above the floor and within the car. The action is as follows: At first on beginning to heat up, all the pipes and both tanks are full of steam. As soon as condensation has taken place, sufficient to seal the entrance to the small pipe, the steam in the upper tank is separated from the other. Then, on cooling, the pressure decreases, and the excess of pressure in the lower tank sends the water up into the upper tank. The original idea of putting the tank under the car was to make it serve as an auxiliary boiler, but Mr. Houston, recognizing the objections to having a tank under the car, is now fitting up a large number of cars with a similar device, where, however, there is no auxiliary boiler, and where in place of the lower tank there is a small box or trap just below the upper floor, from which proceeds the small pipe, and the upper tank is not set on the floor, but somewhat higher up. The effect of this is that the condensation water is collected in this upper tank, and thus it is in no danger of freezing, and also it gives out some heat through the walls of the tank into the car. It also furnishes hot water for cleaning up. When the car is set off, a sufficient number of valves are opened wide, and the water is all drained off.

No system of draining off the condensation water can be efficient without the means of properly venting the pipes and letting in air.

MAIN PIPE; RADIATING PIPES AND VALVES.

It seems to be most common to use one and one-half inch pipe for the main pipe. Some have used one and one-fourth inch, but one and one-half inch is more common and gives better satisfaction generally. As to the location of this pipe, it is most frequently placed under the middle of the car, wrapped, of course, in hair felt, or some other non-conducting covering. A better way is to place it between the sills and box it in. In this case it is also wrapped, and the surrounding woodwork should be protected by tin or sheet iron. Another and a better way yet is to place it inside the car on one or both sides; in this case it is not wrapped, but forms part of the radiating surface. The chief objection to this last arrangement is that the heat cannot be entirely shut off from one car without shutting it off from all the cars behind it. Another objection is that the passages are a little more crooked; but this is more than counterbalanced by gain in heating power.

On account of the exposed conditions of the car the radiating surface should be considerably more than would be required in a building. On the Boston & Albany road they have one square foot of heating surface for each twenty-five cubic feet of space in the car, or one square foot of heating surface for every thirteen square feet of exposed surface, including floor, roof, and walls. Of the 2265 square feet of exposed surface 240 are glass. On the Old Colony road they have one square foot of heating surface for each twenty-six cubic feet of space in the car, or one square foot of heating surface for each thirteen and four-tenths square feet of exposed surface. Of the 2344 square feet of exposed surface 277 are glass. The above are reasonable proportions.

In regard to the size of the pipes to be used for radiating pipes, an opinion based upon experiment cannot be given. As the following conclusions are based on observations only, they may be imperfect. It is desirable to so arrange the pipes that there may be as little obstruction as possible to the flow of steam. It is probable, therefore, that one and one-half inch pipe is better than one and one-fourth inch, and two-inch pipe better than one and one-half inch. The larger the pipe also, the shorter will be the length of pipe needed. Moreover, there is reason to believe that where two-inch pipes are used, the time of heating up is less than where one and one-fourth inch pipes are used, and also that the proportion of the pressure realized in the last car is greater. Nevertheless, in the cases of one and one-fourth inch pipe which have been examined there have been other causes for an

increased resistance. Hence it may be that all necessary freedom of circulation can be secured with one and one-fourth inch pipe, though indications point to two-inch pipe as preferable.

The connection between the main steam pipe and the radiating pipes should be as free as possible, and it is desirable that the steam should not have to pass through the radiating pipes of one car before entering the main pipe of the next. So also the condensation of each car should be drained off from that car and not returned to the main pipe. The most primitive way is to have in the main pipe near the middle of each car a cross from which proceed the pipes that lead steam into the radiating pipes on each side of the car; then a globe valve is placed in the main pipe on each side of the cross, its only use being to shut off the rear end of the main pipe when the car is the last car in the train.

Such a system works all right if proper care is taken of it, but it is desirable to reduce the number of valves needing attention, and also the danger of leakage by the use of some more complicated single valve, which can perform the necessary service and at the same time be more free from liability to leak. In choosing between the different devices, the amount of the reduction of pressure of steam in its passage through the train is therefore a most important consideration, and this should be as small as possible.

A train should be heated without having high-pressure steam on any car; for if, in order to get sufficient heat into the rear car, it is necessary to have a very high pressure in the first car, in that car there will be the danger of an explosion or of blowing off an end. This consideration also enforces the importance of freedom from resistance. The above is also a reason why a good and reliable reducing valve is a desideratum.

EXHAUST STEAM, LIVE STEAM, OR WATER.

The main difficulty with any system of heating by means of water stored in a reservoir, and heated up by steam outside or inside of it, is the length of time required to heat up the cars in cold weather, because while the steam is heating the water it cannot be heating the car to the same extent as it would if not required to heat the water. A hot-water circulation seems to be better adapted either to heating in moderate weather, or else in cases where individual heaters, like the Baker or Johnson heater, are used, and fire is kept in them nearly all the time.

Exhaust steam is very much needed in the locomotive to generate the draught, and it is certainly a serious question whether any of it can be spared to heat the train.

Any system which attempts to heat with exhaust steam is liable either to cause back pressure on the cylinder or else to spoil the draught. Either of these results is very detrimental to the running of the locomotive. Mr. Houston of the Atchison, Topeka & Sante Fe Railroad has used a system utilizing exhaust steam which is open to the above objections to a slight degree only, if at all. The steam is taken from a point about half-way down the exhaust nozzle by a pipe, and enters the pipe in the direction of its flow, thus utilizing its velocity to send it into the train pipe. A series of check valves retain the maximum pressure in the train.

He also uses a peculiar valve by means of which exhaust steam is admitted whenever the throttle valve is open, and whenever the throttle is closed live steam is used, so that the heating up is all done with live and not exhaust steam, and it is perfectly possible at any moment to shut off the exhaust steam and admit live steam instead.

The system, at the time when the examination was made, had been run on three cars in line only, and is reported to have succeeded in the very coldest weather in heating them thoroughly. Whether there will be sufficient exhaust steam to spare to heat a line of eight or ten or twelve cars is not yet demonstrated, nor have any tests yet been made to determine the effect, if any, upon the back pressure or upon the draught, though none has been noticed in the running of the engine.

Another difficulty is that when exhaust steam is used, oil is liable to get into the pipes and valves, which therefore need frequent cleaning.

All the above leads to the conclusion that the main reliance must be upon live steam, with a possible use of exhaust steam when, and if, it can be spared.

No return system has been investigated, as none is used on the railroads of the State.

AUXILIARY BOILERS.

The roads that have auxiliary boilers under their cars are making less and less use of them. The plan of having the fire under the car is believed to be radically wrong, and more dangerous than a fire in the cars, for it is not accessible during the run, and if the train is stalled in a snow-drift, the auxiliary boiler becomes practically useless.

REGULATION OF HEAT IN MODERATE WEATHER.

There is not in use on the Massachusetts roads any successful device for regulating the heat in moderate weather, other than by shutting off the steam and opening the ventilators and windows. Mr. Houston has

a scheme in contemplation, but has not yet put it in practical operation, and one has been in use the past winter on the Chicago, Milwaukee & St. Paul, but no personal examination of it has been made.

CARE OF THE CARS WHEN STORED AWAY.

As the locomotive generally cannot be attached to cars for such length of time before they are to start as will be required to heat them, it will be necessary at all the principal stations, and, perhaps, at all the stations where cars are left, that there should be either a stationary boiler or else one or more locomotives specially devoted to heating cars, and that pipes or hose should lead from the boiler to those points where cars will stand when they are to be heated. For this purpose an ordinary low-pressure boiler would be sufficient, and it could also be used to heat the station.

This method is adopted by the Boston & Albany at Boston and South Framingham, and by the Connecticut River at Springfield. It would certainly be the method to be adopted by most roads at all stations where they have occasion to leave cars in the cold for any length of time. Some roads, especially the Old Colony, are, however, obliged to leave cars at so many stations that it would be at least a hardship to be obliged to have a stationary boiler at each one of them.

It is an open question whether there is any other feasible means of heating up cars at the smaller stations where only two or three cars are left.

It having been suggested that oil stoves might be used for this purpose, the following experiments were made to determine their heating powers.

Two oil stoves, each having four burners, each burner being four inches long, and each stove having a sheet-iron radiator, were placed one at each end of a car sixty feet long with the following result: —

EXPERIMENT NO. I.

Stoves put in and lighted, —

9.55 A.M.	Outside temperature,	38.3
	Average temperature in car,	42.4
11.30 A.M.	Outside temperature,	39.2
	Average inside,	61.9
12.10 P.M.	Outside temperature,	39.2
	Average inside,	63.2
1.05 P.M.	Outside temperature,	39.2
	Average inside,	67.4

The fire was then extinguished, and another observation taken at

3.45 P.M.	Outside temperature,	36.5
	Average inside,	52.7

EXPERIMENT NO. 2.

Same arrangements, except that the radiators were not used.

March 14. — Fire started, —

10.05 A.M.	Outside temperature,	36.5
	Average inside,	35.9
11.30 A.M.	Outside temperature,	35.6
	Average inside,	50.0
12.30 P.M.	Outside temperature,	36.5
	Average inside,	53.2
2.30 P.M.	Outside temperature,	36.5
	Average inside,	56.4
4.30 P.M.	Outside temperature,	37.4
	Average inside,	56.6

This experiment indicates the importance of the radiators.

EXPERIMENT NO. 3.

In this experiment an extra three-burner stove was used in addition to the other two, all being provided with radiators. The following are the results: —

March 17. — Fire started, —

10.45 A.M.	Temperature outside,	33.8
	Average inside,	45.8
11.45 A.M.	Outside temperature,	33.8
	Average inside,	57.2
1.30 P.M.	Outside temperature,	34.7
	Average inside,	63.8
2.15 P.M.	Outside temperature,	35.6
	Average inside,	65.6

The experiments with oil stoves were therefore not encouraging. The odor, also, would be objectionable, if they were not properly trimmed.

INDIVIDUAL HEATERS.

These hardly come within the scope of this report, as the object has been to examine the methods of heating cars by the use of steam taken from the locomotive, and not by means of fires in the cars. Nevertheless, they come in incidentally, to some extent, for the following reasons: —

1. Some of the steam-heating systems, notably the Wilder, and the jet system, used on the New York & New England, involve the use of the Baker heaters.

2. Another proposition is, to attach to the system an individual heater which could be used in case of an emergency.

In the former case, whether the heat is derived from the locomotive or from the heater, a hot-water circulation is used to do the heating. Moreover, in this case, the heating up of the cars is generally done by building a fire in the heater and letting it die out just before starting. This, of course, involves the liability, if there is any carelessness on the part of the employees, of starting out with fire in the cars. Moreover, if fire is not kept in the heater all the time when the cars are in the shed, there is danger of the water freezing, and hence of bursting the pipes.

On the other hand, the second system is one which involves the use of steam, and not of water for heating. Hence the heater in the car is not used as a rule; the only occasion when it is used being during a blizzard, when the cars are snow-bound and detached for some reason or other from the locomotive. This is an important item to provide for in the West, where such things are of frequent occurrence. On eastern roads, however, such an emergency so rarely occurs that it is questionable whether it would be worth while to make provision for it. Of course, if there are no individual heaters, it would be the duty of the locomotive to stay with its train when caught in a snow-drift. In order to insure a supply of coal it has been suggested that the heater should be of such a kind that the coal burned on the locomotive could be used in it.

If a heater is used, there would be much less danger in using an open than in using a closed circulation, for the latter is liable to produce a heavy pressure on the pipes and perhaps lead to an explosion.

AMOUNT OF STEAM USED IN HEATING CARS.

There are all sorts of opinions and statements in regard to the amount of steam taken from the locomotive to do the heating. Some claim that the steam cannot be spared, and that the engine cannot make her time if called on for this extra duty; and others, that it makes no perceptible difference in the running of the locomotive. Some even go so far as to say that all steam required for heating can be furnished through a hole in the boiler no larger than a pinhole. That neither extreme is correct is shown by the following experiments. It did not

seem to be worth while to undertake any very precise work to compare the amount of steam used, when this, that or the other appliance is used, or this, that or the other size, or amount of pipe, for it does not seem that, in the present stage of development of steam-heating, such information is required.

The winter was so far advanced when the investigation began that there was not sufficient time to perform the work in such manner as to obtain indications as to the effect of each appliance upon the amount of steam used, and, moreover, at the beginning it was not at all certain whether the amount of steam used would form an element of any importance in the question.

Such an investigation would have involved some very careful work in getting the same conditions of temperature outside and inside of the cars, and also in studying the effect of the wind. Other conditions also would have been required, which would have been at best difficult to obtain, and which could only have been obtained, if at all, with an empty train, and, if this were used, the results would not be those of practice.

The attempt, therefore, has been made to obtain as nearly as may be the amount of steam used in an ordinary run in cold weather, leaving the train hands to manage the heating, as they usually do, which means that the cars are sometimes too hot and sometimes too cool, but generally somewhere near right. It also means that if they become too hot they will be cooled off, either by shutting off steam or by opening ventilators or windows.

In view of all the above, the problem has been to determine, approximately, the amount of steam used with sufficient exactness to show whether it is likely to be a serious tax upon the locomotive. The apparatus used consisted of two lengths of six-inch flange pipe, as shown in the tracing, bolted together with a brass disk between them, — this disk containing a two-inch hole, into which is screwed a nicely made circular orifice. The steam enters the apparatus at one end and passes through the orifice, and then from the other end of the apparatus it passes into the main train pipe. The pressures in the different parts are regulated by two globe valves, — the first controlling the admission of the steam to the apparatus, and the second placed just beyond the apparatus to control its pressure on the train, so as to make it correspond to that ordinarily used. The pressures on each side of the orifice were shown by test gauges, and these and also the boiler gauge were read every five minutes during the run. Afterwards, when the engine was in the round-house, the same conditions were repeated as nearly as possible, with the following exceptions : —

Instead of delivering the steam into the train pipe it was delivered into a short pipe with another globe valve, which regulated its pressure in this pipe to correspond with the pressure on the train. The prolongation of this pipe extended into a barrel partly full of cold water, where it was condensed and weighed. The steam for the train being taken from the dome it was assumed to be dry. At any rate it did not seem to be worth while, at that stage of the problem, to test it with a calorimeter.

The steam was taken from the combination from which proceed all the pipes that take steam from the locomotive except the dry pipe. It is probable that the results were somewhat affected by the current in each of these pipes, which was, of course, more or less irregular; but these irregularities are precisely those which occurred on the run.

A description of the experiments and the averages of the results are given, and some comments made upon them.

The boat train on the Old Colony road and its locomotive, which Mr. Lauder kindly consented to have used for the experiment, was at the time running with four steam-heated cars, viz. : a combination baggage and second-class car, a smoker and two passenger cars, all fitted with the Sewall system, including the Sewall coupling and the new Sewall valve. There are two other passenger cars which are fitted with steam-heating apparatus, but they are only used in the busy season.

The four cars stated above are first heated up by the engine, which is generally attached about 3 P.M. The train leaves the yard at 5.10 P.M., reaches the depot at about 5.30 P.M., where it remains without the engine for half an hour, and starts at 6 P.M. for Fall River, arriving there about 7.20 P.M.

There are, therefore, four cars in line during the heating up. When the train leaves the depot, however, two baggage cars are placed between the combination car and the engine. One of these cars is a platform, and the other a box, car. They are not heated by steam, but each has a steam pipe passing underneath, so that the steam has to pass through this pipe the length of these two cars before entering the four steam-heated cars. The preliminary experiment to determine the size of orifice required in our apparatus was made on Feb. 28, 1888.

An orifice one-eighth inch diameter was put in, and on trying to heat up the cars in the afternoon, by letting the steam pass through this orifice, it soon became evident that they could not be heated in any reasonable time, if at all, so the apparatus was cut out of the circuit, and the train was heated up in the usual way.

The experiment was then made to see if the one-eighth inch orifice

would be large enough to use on the run; but as forty pounds pressure was needed on the train pipe in the cab, and as it was not possible to get more than five by the use of that orifice, it was demonstrated that an orifice one-eighth inch diameter was too small for the four cars. Next, a one-half inch orifice was substituted for the one-eighth inch, and this worked all right. It was none too large; and it is probable that if the experiment had been made with six cars, with the thermometer below zero, a larger orifice yet would have been needed. As it was, the one-half inch orifice was used in all the tests. The results are as follows:—

February 29. Heating up Cars in Shed. Four Cars in Line.

Pressure on train pipe in the cab,	40.00 lbs.
Let on steam,	3 h. 08 m.
Steam through main pipe,	3 " 12 "
Condensation through first car,	3 " 15 "
" " second car,	3 " 21 "
" " third car,	3 " 30 "
" " fourth car,	3 " 52 "

The temperatures were as follows:—

Hour.	First Car.		Second Car.	Third Car.	Fourth Car.	Outside.
	Baggage Section.	Second-class Section.				
3-00	45	45	37	37	37	31
3-15	45	46	..	..	..	..
3-30	57	63	50	45	36	30
4-00	63	70	63	60	54	30
4-15	66	77	68	66	61	30
4-30	66	81	72	71	65	30

The last car reached a required temperature of sixty-seven and a half degrees at 4.34. The pressures in the cab were as follows during this time:—

Average boiler pressure,	152.8 lbs.
Pressure on first part of apparatus,	100 "
Average pressure on second part,	90 "
Pressure on train pipe in cab,	40 "

In the round-house two experiments were made, repeating as nearly as possible the above conditions, and the average result was, that the steam condensed in one hour twenty-six minutes, being the time consumed in heating up the train, weighed 386 pounds.

EXPERIMENT NO. 2.

Trip, Boston to Fall River (four steam-heated cars), Feb. 29, 1888.

Time of starting,	6 P.M.
Reached Fall River,	7.25 P.M.
Time of Run,	1 h. 25 m.
Average boiler pressure,	157.6 lbs.
Pressure on train pipe in cab,	40 "
Average temperature outside,	27°
" " of baggage car,	52°
" " of second-class car,	67°
" " of smoker,	69°
" " of third car,	71°
" " of fourth car,	66°
" " of smoker and passenger cars,	69°

The average of the round-house tests gave 474 pounds of steam in one hour and twenty-five minutes, which was equivalent to 334 pounds per hour. During the trip a number of the ventilators were open.

EXPERIMENT NO. 3.

Trip, Fall River to Boston (four steam-heated cars), March 1, 1888.

Time of starting,	5.35 A.M.
Reached Boston,	7 A.M.
Time of run,	1 h. 25 m.
Average boiler pressure,	157.6 lbs.
Pressure on train pipe in cab,	40 lbs.
Average temperature outside,	27°
" " of baggage car,	52°
" " of second-class car,	67°
" " smoker,	68°
" " third car,	70°
" " fourth car,	66°
" " smoker and passenger cars,	68°

The average of the round-house tests gave 434 pounds of steam in one hour and twenty-five minutes, which is equivalent to 306 per hour.

The ventilators were not open as much as on the evening of the 29th of February.

EXPERIMENT NO. 4.

Trip, Boston to Fall River (five steam-heated cars), March 5, 1888.

Time of starting,	6 P.M.
Reached Fall River,	7.17 P.M.
Time of run,	1 h. 17 m.
Average boiler pressure,	159.7 lbs.
Pressure on train pipe in cab,	40 lbs.
Average temperature outside,	30°
" " baggage car,	57°
" " second car,	67°
" " smoker,	63°
" " third car,	66°
" " fourth car,	64°
" " fifth car,	66°
" " in smoker and passenger cars,	65°

The average of the round-house tests gave 419 pounds in one hour and seventeen minutes, or 326 pounds per hour. This is not very much more than was used with four cars on the other trips, but the weather was warmer and the cars were not as well heated.

EXPERIMENT NO. 5.

Fall River to Boston (five steam-heated cars), March 6, 1888.

Time of starting,	5.20 A.M.
Reached Boston,	6.50 A.M.
Time of run,	1 h. 30 m.
Average boiler pressure,	158.2 lbs.
Pressure on train pipe in cab,	40 "
Minimum temperature outside,	14°
Average temperature outside,	19°
" " baggage car,	53°
" " smoker,	61°
" " third car,	70°
" " fourth car,	67°
" " fifth car,	65°
" " in smoker and passenger cars,	67°

The average of the round-house tests gave 570 pounds of water in one hour and thirty minutes, or 380 pounds per hour.

It is to be observed, also, that the last two cars were not really warm

enough; their temperatures on arriving in Boston were sixty-six degrees and fifty-seven degrees respectively, which shows that more than forty pounds pressure on the train pipe in the cab was needed. This was not furnished because the electric apparatus for signalling to the cab was out of order.

SUMMARY.

The amounts used per hour in the four trips were as follows: —

First trip, 4 cars thoroughly heated,	334 lbs.	27°	outside.
Second trip, 4 cars well heated,	306 "	27°	"
Third trip, 5 cars insufficiently heated,	326 "	30°	"
Fourth trip, 5 cars poorly heated,	380 "	19°	"

The experiments, though not made with an extreme degree of accuracy, nevertheless give the results to be expected in practice with steam-heated cars fitted up like those experimented upon with a sufficient degree of approximation to justify an opinion as to the tax upon the power of the locomotive, and they indicate that the amount of steam required is by no means inappreciable, and, on the other hand, that this amount is not, as a rule, a serious tax upon the locomotive, especially in view of the fact that at the time when steam heating is most needed, *i.e.*, in the coldest weather, the travel on most roads is light.

EXPERIENCE OF THE ROADS.

The roads which have been visited are: —

1. Boston & Albany.
2. Old Colony.
3. New York & New England.
4. Boston and Providence.
5. Fitchburg.
6. Connecticut River.
7. Providence & Worcester.
8. Boston, Revere Beach & Lynn.
9. Atchison, Topeka & Santa Fe.

Boston & Albany. — This road has been using nominally the Martin system, the main pipe being one and one-half inches diameter and under the middle of the car; the radiating pipes being two inches diameter, two rows (*i.e.*, one main and one return) on each side of the car, and spurs under most of the seats. The valve connecting the main

pipe with the train is a three-way plug cock. The condensation of each car is disposed of separately, by a trap of the thermostatic type.

The road has been using a number of Martin couplings, but they leak badly. The Westinghouse one and one-half inch air-brake coupling has also been used with good success. At first, soft rubber gaskets were tried, but now hard rubber gaskets are used. The Curtis reducing valve has been used, but it gets out of order, and then lets high-pressure steam into the train.

The Mason valve is now being tried, but has not been used long enough to test it thoroughly. It has been put on an engine where the pressure was only 130 pounds, and there it has worked well, up to date.

One hundred and forty cars and fifty-four engines have been equipped with steam-heating appliances, and trains of eight cars have been heated in this manner.

The stations at Boston and South Framingham are piped from stationary boilers, and at Springfield a special locomotive is detailed for this service. Some traps have frozen up, but the trouble from this cause has not been serious.

On a train of four steam-heated cars the pressure on the train pipe in the cab was found to be twenty pounds, that in the rear car was eight pounds, the temperature outside being twenty-three degrees Fahrenheit; the cars were sufficiently warm. The precaution is always taken to open wide the Martin trap when the cars stop at a terminus. The mode of heating up is to shut off all the cars and let steam through the main pipe till the condensation is cleared out of it, then the radiators are opened successively, beginning with the rear car.

Old Colony. — On this road six cars of the boat train have been fitted up with the Sewall system, including his new valve, and have run on that train during the winter. A main pipe has also been placed under two other cars, one a platform car and one a baggage car, which are always placed on the train next the engine, so that the steam has to pass through the main pipe the length of these two cars before reaching the cars to be heated. These six cars are, one combination baggage and second-class car, one smoker, and four passenger cars. Of these, two of the passenger cars have been used but little, so that generally the train consists of four steam-heated cars.

Seven locomotives have been fitted for steam heating. This has been done so that there should never be any danger of having the boat train cold. All the seven locomotives were at first equipped with Curtis

valves; one of them failed, and it was replaced by a Mason valve, which also got out of order.

The traps have nearly all been taken off and globe valves substituted, and they work better than the traps. It requires at least two hours to heat up a train of six cars from zero degrees. The heating up is accomplished as follows: First shut off all the cars and let steam through the main pipe, then begin with the car nearest the engine and get the condensation through that, then open the next car and so on.

One of the chief difficulties met with on this road is the fact that there are no less than thirty-eight stations where they leave cars in the cold, the number of cars left at any one being from two to twenty. If continuous heating were introduced, probably a large number of these would have to be piped up with a stationary boiler or the equivalent.

In heating up the train from forty to eighty pounds pressure is used on the train pipe in the cab, and in running with four cars about forty pounds pressure is generally used on the train pipe in the cab, while if it is very cold sixty pounds is used. The experiments for weighing steam having been made on this road, the working of the system has been examined pretty fully.

In one case the elbows in the pipes connecting the main pipe with the cars were found to have burst, probably by freezing. This car had a trap which probably did not drain.

The Sewall coupling is used and it is generally tight; but occasionally, when going round a curve, it pulls out and leaks, and then gravity is not able of itself to close it, so that it has to be punched in order to secure tightness.

New York & New England. — On the New York & New England road there are twenty-seven steam-heated cars; three of them are fitted with the Sewall system with the old style valve, and the remaining twenty-four are fitted with the safety system. Of these twenty-four, eleven are fitted with the jet system.

On all the cars the Westinghouse air-brake coupling with a hard rubber gasket is used, instead of a soft rubber one, and these couplings have worked uniformly well. The valve used in the cab is not a reducing valve but simply an ordinary globe valve.

In the Sewall cars each car is drained separately, and in two of them the Sewall trap has been replaced by one of the thermostatic type made by Mr. Henney, the superintendent of motive power of the road. The main pipe for both these and the safety cars is one and one-fourth inch, and Mr. Henney considers this size large enough and finds no difficulty

in realizing a good portion of the pressure in the rear car of six or seven.

In the case of the safety cars (not the jet system) he stated that with the steam in the coil and the water in the drum he did not succeed in obtaining a circulation, as the current of water was short circuited. He then changed and put the water in the coil and the steam in the drum, and now has no difficulty.

In the case of the cars fitted with the jet system, where a jet of steam is forced into a water pipe near the Baker heater, an overflow has to be attached to the drum of the heater, which drains off enough water to make up for the steam added, and this overflow must be left open, thus giving an open circulation; but there is a valve in this overflow pipe which can be closed when steam is not on and it is desired to run the heater under pressure by means of a fire. Mr. Henney is now putting his main pipes inside the car on one side, and the overflow of the heater drum forms his trap. Hence he may be said to have both main pipe and trap inside the car, in the case of the jet system cars.

On the other hand, in the case of all the safety system cars, the heating up is practically done by means of fire in the heaters, and indeed fire is kept burning in these at all times when the locomotive is not attached, but is allowed to die down and is dumped just before starting.

The following experience is instructive: On a very cold day the locomotive was put on to heat a train at 8 A.M. The traps were at that time all frozen up. The train started at 8.30 A.M. The train consisted of a baggage car, smoker and one passenger car, all fitted with the Sewall system, while the other cars were heated by Baker heaters. The baggage car had a thermostatic trap, while the other two had the Sewall trap, and these two were both frozen up on starting. The cars were naturally cold on starting. The temperature of the smoker reached sixty-six degrees by 10.20 A.M., and the passenger car was still longer in heating up.

No reducing valve has thus far been used, but one of the piston variety is soon to be tried.

Boston & Providence. — On this road the Sewall and the Gold systems and a system of Mr. Richards, the master mechanic of the road, are being used and various experiments are being tried. The Sewall couplings are used throughout. The Ross and the Curtis reducing valves have been tried and failures have been experienced with each. The Mason valve was also tried for a short time, and in one instance failed, owing to the valve getting clogged up with dirt. Mr.

Richards has also been trying to get up a valve made by means of two pistons, but thus far he has been using it mainly to fix the maximum pressure in connection with a throttle valve to regulate the pressure. The trouble he has had with the Ross and the Curtis valves has been that they get out of order on account of the delicacy of the parts. He has used a great variety of traps and has had them all freeze up, and he is now adding a valve to drain the water and to enable the trap to be thawed out.

In heating six cars in zero weather on the run, Mr. Richards' aim is to limit the maximum pressure to forty pounds pressure in the cab.

Mr. Richards' system is peculiar, mainly in the piping. The main steam pipe goes inside the car, near the floor in passenger cars and overhead in baggage cars. This main steam pipe forms one of three pipes of the radiator. There are two cross-overs, the traps being in these cross-overs. By another system which he has tried a branch of the main pipe passes on each side of the car, and there are four radiators in each car, the traps being at the middle of the length of the car.

The following record was made on a train to Providence where there were, 1st, baggage car, 2d, smoker, both having Mr. Richards' system, 3d, passenger car, having also steam heat when it could get it, but on this occasion having a fire in a stove. The train started at 9.45 A.M. The locomotive had been on since 9 A.M. Sewall traps were all frozen when the steam was let on. There was one Curtis trap which was not frozen on this occasion. Temperature of smoker at starting was forty-seven degrees and of passenger car fifty-five degrees; at 9.55 smoker fifty degrees, of passenger car fifty-seven degrees.

The company has in use about twenty Curtis reducing valves and two Mason, but recourse is had to throttling a good deal.

There are about fifty Gold, forty Sewall, and twenty Richards' baggage and passenger cars equipped with steam heat. At one examination there were forty pounds in the cab as far as Mansfield, and then twenty to twenty-five pounds. After passing Mansfield the third or passenger car showed seven pounds on the gauge.

In the case of the Gold system cars it took a long time to heat the train.

Fitchburg Railroad. — The Sewall system is being used on a number of cars, with the following peculiarities: —

1. No reducing valve is used, but only a throttle. 2. No traps are used, but only globe valves. 3. Near each end of the main pipe is a plug cock, by means of which the steam can be shut into the car to

keep the car warm while standing. Some of the Sewall cars are piped with one and one-quarter inch pipe, while others have, in part, one-inch pipe. As far as inquiry and observation went, it seemed that there was much more difficulty in heating those that had the one-inch pipe than those that had one and one-quarter inch pipe. In cold weather about sixty-five pounds pressure in the cab is carried. The engineers and train hands do not like the Sewall couplings, because they leak whenever they get twisted in going around curves, etc.

Connecticut River Road. — This road may be said to be the pioneer in heating cars by steam from the locomotive, having had it in operation since 1881. They have in all forty-five cars, of which twenty-seven are heated by steam heat. They use what is called the Emerson system. The piping consists of two rows of two-inch pipes on each side of the car with spurs or U's under each seat, thus being just like the Martin piping. No reducing valve is used, and no traps. As to couplings, they use three different ones indiscriminately, all made by some of their own people, — either the Emerson, the Hitchcock, or the Barrett, all of which seem to be reasonably tight; the two last have gaskets, while the first has metallic surfaces coming together. None of them uncouple automatically when the cars break apart.

In the globe valve, under the car, there is a very small hole (one-thirty-second of an inch) above the valve to take care of the drip while running, and when that is not enough the valve is opened a little.

Different reducing valves have been tried, and examination was made of one which had been working three months. It had got out of order so that a throttle was resorted to, and it was used as a safety valve only. The valve was subsequently taken off and repaired, and it was found that the difficulty was due to dirt getting into some of its delicate parts. In this case it was a Mason valve. There is a stationary boiler at Springfield and cars are heated there by that means, while at Northampton a switching-engine is used for heating.

As a rule only three cars are heated in line, though every Saturday a train is sent out with six cars and no trouble has been experienced with them. On a trip on a train of two cars from Springfield to Northampton and back, the temperature outside at Springfield being three degrees below zero, the cars were quite warm.

Only two cars on this line are fitted up with auxiliary boilers under the cars, and they are only used when the cars are left at a station where there is no means of heating them otherwise.

Providence & Worcester. — On this road the Martin system is used on some cars and the Sewall system on others, and very good success has been experienced with everything. The cars at the Providence end of the route are heated by a stationary boiler, and at Worcester by a locomotive. A tank, holding about twenty-seven gallons, is carried under the trap under each car to catch the drip, so that it shall not fall on the platforms and freeze, thus forming slippery places at the stations.

Boston, Revere Beach & Lynn. — This is a narrow gauge road and the cars are very nicely fitted up with steam-heating arrangements, devised by the superintendent, Mr. C. A. Hammond. The coupling used is one especially devised by Mr. Hammond and seems to serve its purpose well. The two parts of the couplings are not duplicates, and on this road it is not important that they should be, inasmuch as the cars are never turned round. Of course, uniformity with other standard gauge roads in the matter of the coupling is not at all necessary on a narrow gauge road.

The piping used is just like that of the Emerson or of the Martin system, except that there are no spurs under the seats. The main pipe is outside of and under the car and on one side. No reducing valve is used, but merely a throttle valve, and also a safety valve to warn the engineer if the train pressure becomes too high.

Only two cases of frozen traps have been reported during the winter, as the necessary arrangements have been provided to keep the cars warm at all times, whether running or idle. At Boston there is a stationary boiler and the necessary piping, and at Lynn one of the locomotives is used instead of a stationary boiler.

The Curtis trap is used and has worked well.

There are in each car about 125 square feet of heating surface to about 3000 cubic feet of car or 1 : 24.

A complete record of the temperatures of the cars on all trips and also of all their mishaps is kept. The greater part of the mishaps seem to be from parting of hose. Twenty-three cars in all are fitted with steam heat.

Atchison, Topeka & Santa Fe. — In accordance with the directions of the Board, a trip to Chicago was made to examine the system on trial on the Atchison, Topeka & Santa Fe Railroad. Nearly two days were spent with Mr. George A. Houston, who showed me every courtesy and gave me the opportunity to examine everything in the fullest possible manner. He himself was commissioned by the road about a year ago

to examine all the systems of heating cars by steam then in use or proposed, and then to devise a system that should be the best for their purposes. He was given full freedom to experiment as much as he desired, and, as a result, he has been making a great variety of experiments during the last year, and he showed all that he is now using, and also what changes he is making in the cars now being fitted up. At the time of my visit he had heated only three cars in a line at most, but was fitting up a large number with steam-heating arrangements. Most of his devices have already been described at different places in the body of this report, and attention has been called to his mode of getting rid of the water of condensation, which is in my opinion the feature of special excellence in his system; but it may be well to summarize in a few words what he has done and is doing.

Thus far he has been using exhaust steam when the engine is running and live steam when it is standing still, and always using live steam for heating up. He states that he has had no difficulty in heating up three cars and keeping them warm in the very coldest weather in that region.

The mode of disposing of the condensation has been already described. He intends that the tank into which the water is to drain should form the shell of a heater in which fire can be made whenever from any cause the locomotive is obliged to leave the train for any length of time, as may happen in a Western blizzard.

He has also a scheme for heating the cars in moderate weather, when it is only necessary to raise their temperature ten degrees or thereabouts, but this had not been put into operation.

When the automatic valve (referred to before) was inside the smoke chamber, some trouble was experienced with grease which clogged it up, but it is now placed outside where it can be opened and cleaned at any time.

The result of all these experiments will undoubtedly be a more extended use of continuous heating during the coming winter, and a general improvement in the appliances and in the management of the apparatus. The roads will profit by their own experience, and it is to be hoped that this report will help them to profit by the experience of others. The following conclusions may fairly be drawn from what has been done:—

It is very important that there should be uniformity in couplers. The Westinghouse air-brake one and one-half inch coupling, with a hard rubber gasket, works satisfactorily, railroad employees are familiar with its use, and the patent upon it expires shortly.

In regard to everything else, uniformity is not so imperative.

The main pipe should be as well protected as possible. If it must be outside the car it should be thoroughly wrapped. A better place for it is between the sills, and in that place, also, it should be wrapped, or it may be placed inside the car, as is done to some extent by Mr. Richards of the Boston & Providence Railroad and by Mr. Henney of the New York & New England Railroad.

The main pipe, the valves connecting this with the radiating pipes, and the entire system of radiating pipes should be such as to offer the least possible resistance to the flow of the steam, so that high-steam pressure shall not be required on the train. A two-inch or at least a one and one-half inch pipe is desirable to meet this requirement.

A reducing valve which is not liable to get out of order and let high pressure on the cars is a great desideratum.

The amount of radiating surface generally adopted, and which seems to be sufficient, is about one square foot for each twenty-five cubic feet of capacity of the car.

The trap should be protected from freezing, and the best way is to have it inside the car. The trap introduced by Mr. George A. Houston on the Atchison, Topeka & Sante Fe is recommended for examination and trial.

It seems probable that auxiliary boilers under the cars can be dispensed with in this State.

Stations where cars are left should generally be provided with a stationary boiler and pipes for heating the cars.

The amount of steam required is neither excessive nor inappreciable. Nevertheless, the question of economy will be an important element in deciding upon the nature of the appliances to be used when it is desired to heat trains of ten or twelve cars. As a rule, the time when the most steam is needed for heating is the very time when travel is the lightest, and hence when the steam can best be spared.

It is desirable that there should be some automatic device for regulating the heat.

The above is respectfully submitted,

GAETANO LANZA.

BOSTON, March 30, 1888.

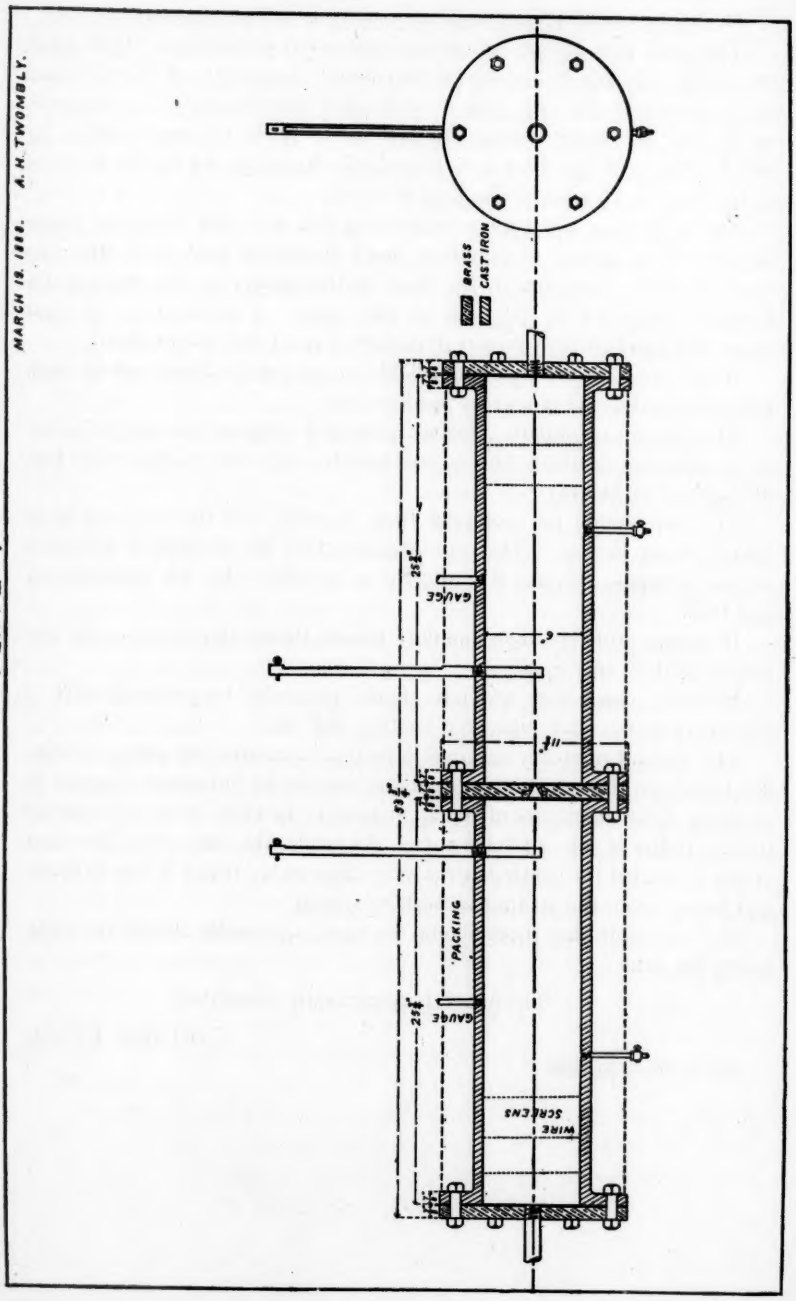
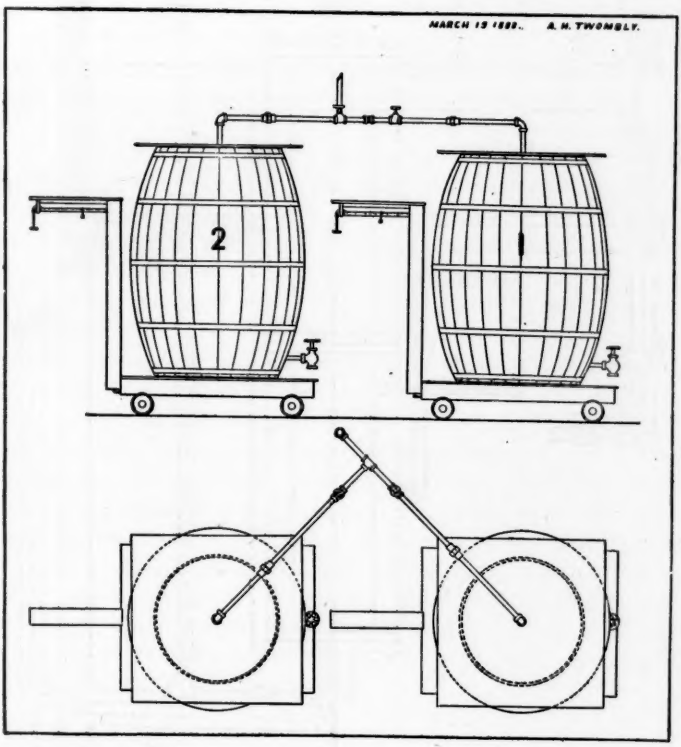


PLATE I
MARCH 18, 1888. A. H. TWOMBLY.
BRASS
CAST IRON
GAUGE
PACKING
WIRE SCREENS


MARCH 15 1887. A. H. TWOMBLY.
2
1

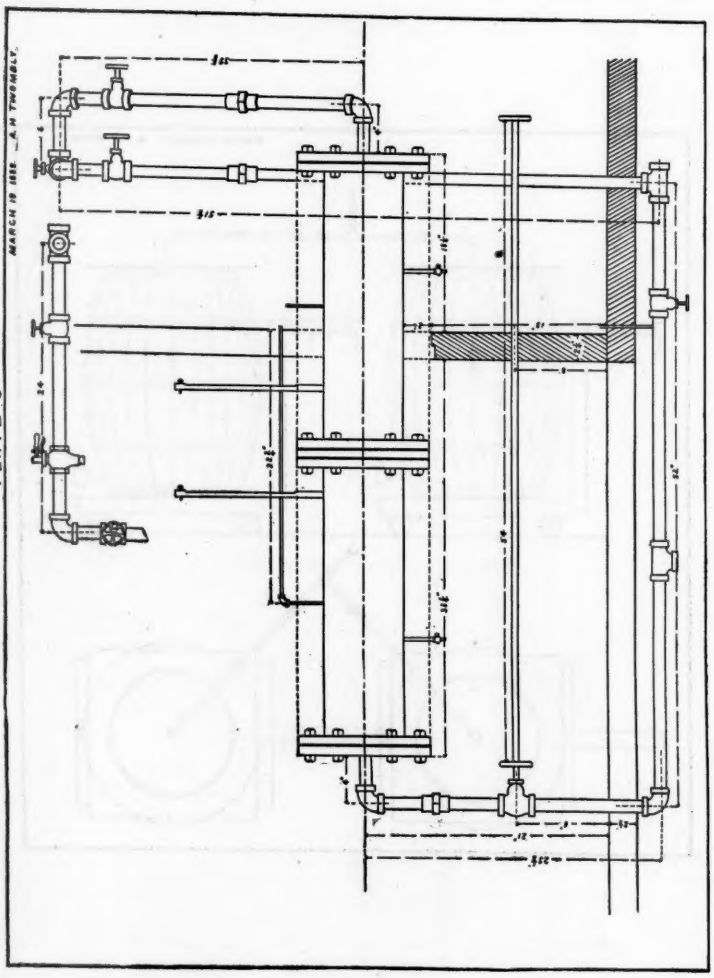


PLATE 3
MARCH 19 1888 A.H. THOMSEN

*THE BIOLOGICAL EXAMINATION OF WATER.**

By WILLIAM T. SEDGWICK, Ph.D.

Within the past five and twenty years a new theory of the causation of infectious diseases has sprung up, and has given to the medical sciences an aspect more rational, more scientific, and more hopeful. Upon sanitary science the effect of the new theory has been still more vivifying; indeed, it is hardly too much to say that sanitary science, so far as it exists practically, has been by it created. Under the older theories of the causation of disease which saw in bodily disturbances only the effects of malign influences exerted by evil spirits, or regarded health as the proper mixture of four internal humors, — blood, phlegm, yellow bile, and black bile, — and looked upon the improper mixture of these four humors as constituting the basis of all diseases, sanitary science obviously found no place. But as soon as it began to be recognized that the seeds of disease are not so much in us as in our environment; that the blind experience of the race as shown by the ideas and language everywhere employed in speaking of the "attacks" of disease had outrun the theories of the wise, recognizing instinctively the true sources of disease as extrinsic, rather than intrinsic; or, in other words, as soon as the original source of disease was perceived to be, not *in* us, but *around* us, sanitary science became at once a possibility and a necessity. In an essay upon the "Advisableness of Improving Natural Knowledge," Professor Huxley has given a forcible example of the attitude of mind which prevailed towards sanitary matters under the older theories of disease, where he contrasts the panic-stricken and awed submission of the dwellers of London to the visitations of the Plague, with their angry passion at the incendiaries who were believed by them to have caused the great fire which not long after devastated their city. To the plague they submitted devoutly and helplessly as to a visitation of the Almighty; to the fire they did not so submit, but, full of indignation, sought to find and rid themselves of, the cause.

Obviously, therefore, it is not a matter of indifference to sanitarians, among whom should be included those having the control or adminis-

*An address delivered before the New England Water Works Association, March 14, 1888.

tration of water supplies, whether this theory or that of the causation of disease is entertained. Every officer and every workman connected with such positions of responsibility is guided, consciously or unconsciously, by some working theory which determines more or less his attitude towards his professional problems; and those best informed are to-day making good use of the so-called "germ" theory of disease. This theory holds that the ordinary infectious diseases, such as typhoid fever, smallpox, and measles, are caused by microscopic plants or "*germs*" called *bacteria* or *microbes* or *micro-organisms*, which when they invade or "attack" the human body may do infinite damage, producing sometimes disease and even death. They behave as parasites, feeding upon the tissues, multiplying enormously and producing profound and alarming changes in the bodily economy; yet doing their damage not so much by their presence or, like most parasites, by stealing from the body its necessary foods, but rather by *poisoning* it, unintentionally as it were, by their excreta or the by-products of their activity which, though little understood as yet, are provisionally grouped together under the name of "ptomaines." Accordingly, bearing this "germ" theory in mind, sanitarians have always to scrutinize the environment of individuals and communities in cities, in the country, in workshops, in theatres, on land or sea. Wherever man goes he finds himself in an environment which may or may not contain the seeds of disease, or, more rarely, the poisonous excreta of the organisms of disease. Air, food, and drink naturally carry with them the greatest possibilities of infection, since they are received within the body in special chambers — the lungs, and the other portions of the alimentary tract — specially delicate and adapted for absorption. With the air and the solid food we have at present nothing to do. With the purity of the water, however, we are much concerned.

Biological examinations of water have been made to some extent ever since the human race began. Multitudes of observers have noticed, and some few have studied the fishes and frogs, serpents, snails, clams, and crustacea which inhabit ponds, streams, lakes, and the sea. Others have studied the water-weeds, the sea-weeds, the algæ, and the fungi, and have thus helped to a knowledge of the biology of water. But it is only within a very few years that it has been thought either possible or necessary to count or study the smallest of all the forms of life, the "germs," "bacteria," etc., in water. That our opinions in this respect have changed, is due partly to the adoption of that environmental and parasitic theory of infectious disease of which we have just spoken, bringing with it as it does the recognition that these tiny and invis-

ible organisms may be the agents of disease; and partly to a new and similar theory of putrefaction which teaches that wherever putrefaction is, there will germs be gathered together. I must hasten however to warn you that there are germs and germs. Because there are some scoundrels in human society it does not follow that all men are such. And yet some pseudo-sanitarians whose object is best served by widespread dismay and alarm, sedulously endeavor to impress the public with the idea that germs are everywhere, and that all germs are dangerous.

There is such a thing, however, as slandering bacteria; for while some of them are unquestionably dangerous, and, in the present state of our ignorance about the different species, all of them are more or less under a shadow, there is not the slightest doubt that we depend almost wholly upon bacteria for the reduction to harmless compounds of the great mass of waste organic stuff in nature. If, then, bacteria abound in the waters of our harbor and bay, it is not necessarily with evil intent or with danger to us, but simply because they find there the waste matters of a great city rejected by higher forms of life, but offering to them, the lowliest of living things, an ample feast. In fact, bacteria would seem to possess a wonderful and most beneficial power of reducing to their lowest terms those fractions of organic matter which higher forms are unable entirely to simplify; thereby at once ridding the earth of a nuisance and preparing the way for higher plants to effect a rejuvenation of the worn-out matter. Again, precisely as it is not true that all germs are deadly, or the carriers of disease, it is equally certain that they are not ubiquitous, nor are they always long-lived. They are heavy in proportion to their size, and hence tend to sink in air or water; they are very dependent on food and drink, and therefore may easily be held in check by cleanliness and dryness. In short, while it is easy to dogmatize about them and to portray vividly their possible baneful effects, it should not be forgotten that the human race has developed and even prospered in ignorance, and in spite of them, from the days of savagery until now. Nevertheless, they undoubtedly constitute the chief *raison d'être* of modern sanitary science, and from every point of view their scientific study is most desirable.

It might naturally be asked at this point, How are these exceedingly minute organisms ever studied or counted? and, Of what use is it to count them? or, finally, What may be legitimately expected from the employment of methods for the biological examination of water, in the shape of practical hints which shall be likely to benefit experts in the science or administration of water works? It will be worth while

therefore, first, to describe the methods of the biological examination of water; second, to discuss briefly the value of such examinations to pure science; and, third, to indicate the importance and value of the application of the results of such examinations to the practical problems of our water supplies.

The methods, in principle, are extremely simple; but the art involved is capable of very great refinement and absolutely demands cleanliness, constant care, scrupulous attention to details, and unlimited patience. The object in view, namely, the determination of the number and the nature of the germs in a given water, must never be forgotten, and the better to secure this end-result everything with which the sample of water is to come in contact must be carefully sterilized; that is, all germs must be killed except those favored few which it is desired to study.

In order to illustrate by an example the several steps of the process, I may briefly describe an actual biological analysis of the water supply of Newton, Mass., selected not because it is necessarily typical in its results, but simply because it is fresh in my experience.

The city of Newton finds its water supply in a filter basin 1575 feet long, running alongside the Charles River in the town of Needham. The water in the filter basin is pumped by engines in a pumping station near by, to a reservoir some four miles distant on Waban Hill, from which it flows by gravity to all parts of the city.

In the spring of 1887 Mr. S. R. Bartlett and myself made, in the Biological laboratory of the Institute of Technology, a determination of the number of living bacteria and moulds in the water of the Charles River outside the filter basin, the water within the filter basin, in the reservoir on Waban Hill, and at the tap in the city of Newton; specimens being carefully taken from the different localities on the same successive days. At the same time Mrs. E. H. Richards and Mr. Bartlett carried on a chemical examination of similar samples in the Institute laboratory of sanitary chemistry. In the course of the investigations 145 biological and 117 chemical analyses were made; and all the work done between April 1 and May 15. The method employed in the biological examination was the well-known gelatine plate-culture method of Koch. The usual accessory apparatus was employed, and need not be described. The principle underlying the method is this: By mixing a known volume of the water under examination with a much larger volume of so-called "sterilized nutrient gelatine," the germs in the water are first *separated* somewhat widely from each other in the melted gelatine; and afterwards, when the gelatine has been

poured out on a cool plate, carefully levelled, are *kept* separate and isolated by the stiffened mass. They are thus held securely apart, but may still grow and multiply in the nutrient mass, enriched as it is by meat extract, peptone, etc. At first the gelatine appears perfectly clear and pure; but after a day or two, comparatively opaque whitish or yellowish dots or islands may be detected, due to the rapid, though localized, increase of the germs. Each of these, if caused by bacteria, is called a "colony" and is taken to represent one "germ" in the original water, provided the gelatine used was properly sterilized, *i.e.*, freed from all living germs. Moulds have an equally characteristic though different appearance, and thus both may be recognized after a time and the total number of living "germs" in the original sample readily and accurately estimated.

The water brought in for examination was collected and transported with great care in small glass-stoppered bottles holding about 60 cc. These were carefully cleaned and enclosed in tin canisters made to fit them rather tightly, and all were thoroughly sterilized at 160° C. in the hot air sterilizer. The tin covering prevented any accumulation of dust around the stoppers and allowed without injury considerable knocking about in transportation. In getting the sample of water desired, the bottle was taken from its case, rinsed in the water to be collected, held well under, and filled by lifting the stopper. It was then returned to its tin case and thus conveyed to the laboratory, where the culture was made usually within three hours from the time of collection.

Some of the more important results are indicated in the following tables: —

NUMBER OF BACTERIA PER CUBIC CENTIMETER OF WATER.

1887.	Charles River.	Filter Basin.	Waban Hill Reservoir.	A Tap in Newton.
April 1	315	15		
April 6	267	80	April 11 18	8
April 18	220	48	48	6
April 27	175	40	20	0
May 1	200	15	10	4
May 9	150	64	18	April 29 12
Averages	221	43	23	6

BACTERIOLOGICAL COMPARISON OF THE TAP WATER OF NEWTON AND BOSTON DURING ONE WEEK.

Date.	Colonies per cc., Newton.		Colonies per cc., Boston.	
	A	B	A	B
May 6	0	4	48	60
" 7	6	12	30	44
" 8	Sunday		Sunday	
" 9	8	14	40	52
" 10	0	4	24	60
" 11	2	4	28	32
" 12	0	8	25	35
" 13	12	15	55	65
Averages	6		43	

AVERAGE NUMBER OF BACTERIA PER CC. FOUND AT THE SAME TIME IN THE WATER FROM: —

Newton (tap)	6
Boston (tap on the Back Bay)	43
Mystic (tap in Charlestown)	204
Spot Pond (pond)	38
Spot Pond (tap in Medford)	10
Jamaica Plain (Boston High Service)	52

These, then, were the methods and the bare results of their application. Let us see, in the second place, if, upon scrutinizing and interpreting the results, we do not gain something for pure science.

And let us here keep in mind that, other things equal, richness in bacteria indicates organic impurity; scarcity of bacteria, organic purity; on the principle that "where the carrion is there will the vultures be gathered together"; and further, that however harmless these microscopic vultures may be, we do not wish either to drink them or have them feed upon us.

The first table shows a constant and considerable difference in the abundance of living bacteria in the several waters examined, and indi-

cates a progressive purity in this respect as the water nears the point of consumption. The largest difference between successive samples is that between the river water and that in the filter basin; and this is easily explained by a consideration of the conditions prevailing in each. The river is an ordinary sluggish stream draining a rather thickly inhabited country, and hence is more or less polluted. The filter basin, on the contrary, although dug parallel to the river, and near it, probably gets from it little or no water. This comes instead from the ground in the other direction, owing to the slope of the adjacent country, and especially from eight artesian wells driven in its bottom to a depth of thirty feet, where they penetrate a quicksand and a gravel overlying bedrock inclined towards the river. Thus it comes to pass that the water in the filter basin is sometimes higher than that in the river, and always more constant in temperature; and this, too, it is fair to suppose, is the reason that the water of the river contained 221 germs per cubic centimeter in April and May, 1887, while that in the filter basin showed only 43. The filter basin, even to the naked eye, is clearer and purer than the river, although it often contains a very considerable amount of filamentous algæ, principally Zygnema. It is less easy to explain offhand the progressive decrease of bacteria from the filter basin to the tap. The figures show that of the 43 bacteria which theoretically were drawn by the pumps from the filter basin in every cubic centimeter of water, 20, *i.e.*, nearly 50 per cent, were missing in the reservoir, and 37, *i.e.*, more than 85 per cent, were missing at the tap. From a biological point of view it seems probable that the stock of organic matter, or, in other words, the supply of food for the germs, in this chiefly ground water was originally small and gradually gave out, causing the starvation of the greater part of the bacteria. This hypothesis was afterwards surprisingly and unexpectedly strengthened by the results of the chemical examinations simultaneously carried on, which showed a very pure water in the filter basin and a decline of organic matter from the filter basin to the tap.

No attempt was made to seek out from among these germs, which were doubtless for the most part perfectly harmless, and, as it turned out, even useful, — having destroyed most of the organic matter and then either starved to death or having otherwise perished, — no attempt, I repeat, was made to seek out here the germs of disease. But we look forward to the time, perhaps very near, perhaps a long way off, when we can sample the colonies upon the gelatine and say, after microscopic and further biological study, this one is harmless, that one dangerous,

and so on. But it is not believed by biologists generally that the time has yet really arrived.

And now, finally, how can I better exemplify the practical bearing of the whole subject than by a reference to this same study of the Newton water supply. You have seen that this water improved steadily from the filter basin to the tap. The average number of germs in the filter basin was 43; exactly, as it happened, the same number as in water at the same time from a Back Bay (Boston) tap. The average number in the reservoir was 23, and at the tap in Newton, 6, per cc. What can this mean except that this particular storage, instead of harming that water, actually improved it, so that it was in this respect nearly 50 per cent better in the reservoir than in the filter basin, and at the tap more than 85 per cent better than when it started.

That the chemical analysis did not show an improvement correspondingly great also brings out an interesting point, showing the superiority of the biological test in one respect and its inferiority in another. For *living germs of this particular class* it is trustworthy, and these are of the chiefest importance; but for dead germs, and for infusoria, crustacea, rotifers, worms, algæ, and the like, it is worthless, and hence the superiority in other respects of the chemical examination. I cannot doubt that when we have gone further we shall be able to answer questions of the highest importance, as to the needs and the merits of closed or open filter galleries or basins for special cases; the storage of surface waters; the best means of the disposal of sewage; filtration; aeration; and others of like nature, — work which our excellent and progressive Massachusetts State Board of Health has already actively undertaken.

I have so far spoken only of the *bacteriological* investigation of water, including in it the study of moulds. This is only a part, though doubtless at present the more important part, of the biological examination for which it is often used as a synonym.

We have yet a great deal to learn, however, about the algæ, the sponges, the infusoria, the rhizopods, and the higher forms of life which inhabit or infest (as you please) the sources of our water supply. These are the things which pave the way for bacteria by supplying them with food in the shape of their own dead bodies or their excreta, as organic matter subject to be decomposed. And yet these same organisms are not by any means wholly bad; they, too, in some cases, at least, remove from the waters undesirable matters, so that to praise or condemn in any given case requires the most consummate knowledge, skill, and common sense that an expert biologist can command. Moreover,

this is a field almost unworked, since chemists, bacteriologists and biologists must here go hand in hand, and these experts have as yet hardly come to recognize each the other's importance. Still less, of course, do water boards or private citizens in general understand or recognize the grave importance of such problems; and meanwhile, gentlemen, science, while it offers to you freely whatever it has to give, must depend upon you almost wholly to see to it that its best thoughts and freshest methods are intelligently applied in the practice of every day.

A CRITICAL STUDY OF THE HEATING AND VENTILATION OF THE NEW BUILDING OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

By S. H. WOODBRIDGE, A.M.

I.

Whatever of special interest may attach to the heating and ventilation of this building, aside from that due to the good measure of success attained, inheres, first, in the special features through which the result has been effected, and, second, in the conclusions arrived at through a critical study of those results, as well as through valuable comparison made possible by features of an exceptionally favorable nature.

The paper, therefore, naturally divides itself into two parts, one treating of methods, and the other of results with deduced conclusions.

METHODS.

Nothing worthy of imitation is to be noted in regard to a special adaptation of the building to a previously adopted system of ventilation designed with reference to a maximum efficiency and economy of action. On the contrary, the system must be presented as, in some important respects, a reluctantly accepted compromise made necessary by the fact of its incorporation into the building plans after these were matured and the work of construction was begun. The urgent haste with which the building process was pushed from the foundation, laid in April, to the roof which covered classes the following October, is further responsible for certain defects of detail.

The leading features as sought in the operation of the system may be summarized as follows: —

First. A reversal of the ordinary custom of subordinating ventilation to supposed economy in heating.

Second. A volume and distribution of air supply based on the determined requirements rather than on the cubic capacity of rooms.

Third. A large area of air conduits and passages, and low velocities of air flow.

Fourth. An adjustment of supply and discharge areas such as to produce a slight internal pressure.

Fifth. A location of supply and discharge apertures chosen with a view to the most efficient and economic use of the air supply.

Sixth. An exclusive control of air supply and of room temperature by the engineer.

Seventh. A registering of hourly rate and daily aggregate of steam condensation, as furnishing a basis for critical study in determining the necessary cost of ventilation.

The details of arrangement for securing such results have already been several times described in print, and are here repeated in brief form only for the purpose of giving completeness to the subject which it is the aim of the paper to present.

The building is exposed on all sides, being one of three in an open square. It has a ground outside measurement of $150' \times 90'$ and a height of $70'$. It has, with basement, five stories, and some 40 rooms, ranging in size from 3000 to 60,000 cu. ft. The window area equals one-third of its wall surface, the windows of the west and north sides having double glazed sashes. The walls are of brick, with an average thickness of $18''$.

Under the entire building is a sub-basement divided by the interior walls into four sections (Fig. 1). The floor of each section is made of concrete $4''$ deep, and sloped to a central cistern, into which the water used in washing the floor may drain, and from which it may be discharged by a steam ejector into the sewer. The floor of the basement makes the ceiling of the sub-basement, the height of which is $4'$. The interior walls of the building are made of piers $2' \times 2'$, and $5'$ between centres, extending from the foundations to the roof, and supporting the floor and roof beams; and of shell walls connecting the piers, and with them enclosing flues $3' \times 1'$. As the shell walls end at the basement floor, and the piers at the sub-basement floor, the flues are open into the basement on their two longitudinal sides. There are 47 flues in the interior and 31 in the exterior walls, having an aggregate of 240 sq. ft.

Air for the ventilation of the building enters through an enlarged basement window of 100 sq. feet, situated on the lawn side of the building, as remote as possible from the streets. The air then passes through a battery of steam pipes, having a free area of 120 sq. ft., and is then forced by a fan into a chamber from which the floor is removed, so making it a continuous space with the sub-basement (Fig. 2). The sub-basement thus becomes a plenum whose pressure is determined by the rate of the revolution of the fan, the number of dampers open into flues, and the aspiratory action of the flues.

In order to concentrate the heating system, and to avoid the expense of an extended and ramifying system of supply and return pipes; to avoid the cutting of floors and piercing of walls by the running of pipe, as well as the marring of rooms by the presence of piping and radiators; to avoid damage by leakage, and to make the heating surface accessible for steam control, and for repair, without a disturbance of the occupants, the heating surface is located in the sub-basement.

In passing through the "main coil," 3,500,000 cu. ft. of air per hour may receive an increment of from 0° to 60° in temperature, according to requirement. The purpose of this coil is to raise the temperature of the air sufficiently for the protection of exposed water pipes and for the warmth of the basement floor. The additional heat required is furnished by supplementary coils placed at the base of each flue, the steam flow to which is regulated by a fractional valve manipulated through a covered hand-hole in the basement floor. These coils are made with a free space for air movement through them equal to that of the cross-section of the flue to which they belong, and the heating surface of each coil is adapted to the wants of the room its flue supplies with air. The temperature within the several flues varies inversely as the rate of change of air within the rooms they supply, only one flue temperature being as high in extreme weather as 110°, the majority of flues varying from 70° in mild to 90° in the coldest weather.

The temperature of the air supply is controlled, first at the main coil by the steam pressure within it, which is regulated by a reducing valve, and by the number of its sections used; and, second, at the supplementaries, by the steam pressure carried in the distributing main, by the amount of steam passed into the individual coils, they being so arranged that they may be completely or partially filled with steam at atmospheric pressure; and, lastly, by slide dampers at the bottom of the flues, which admit of passing the air by, rather than through, their coils. The steam is under the exclusive control of the engineer, who receives a record of temperature from all the rooms four times each day.

At the bottom of the flue is a damper by which the air may be shut off from rooms not in use, or the volume of air moved to rooms may be controlled according to their requirement. In the wall of each flue, at five feet above the basement floor, is a hand-hole with glass cover, through which may be seen a thermometer and anemometer placed within the flues. Below the hand-hole is a ring with light chain for the manipulation of the damper.

The air is delivered into rooms through apertures 8′ from the floor, and with a maximum velocity not exceeding 7 to 8 ft. per second, and,

except in warm weather, with a temperature sufficiently elevated above that of the room to cause it to rise to the ceiling, so producing a minimum effect in generating draughty floor currents. So far as practicable the supply is passed into rooms upon their warm side, and the spent air removed at the floor from the same side, and as nearly below the point of entrance as the arrangement and apportionment of flues allow.

The same flue is, in different parts of its length, used for supply to one story and discharge from another above, the two parts being separated by a "header." Many of the flues are also divided into two or three sections, delivering air to or discharging it from separate stories. No one flue or flue section delivers air into two rooms, but discharge flues are not so perfectly separated throughout their entire length.

Discharge flues are provided, at the point of their lower connection with rooms, with check valves of the lightest rubber gossamer, to prevent reversal of draught into rooms by reason of temporary or excessive wind action, or the disturbance of the system's action by the stopping of the fan or the opening of windows, etc. The discharge flues are further provided with valved registers at the ceiling, to be used in warm weather, or for cooling the room when overheated, and a damper at their top for closing to prevent excessive leakage and cooling at night.

The apportioning of the flue areas to each room, as shown in the accompanying schedule, was based on the air supply required for the *maximum* number of occupants and their work. For reasons of policy rather than of satisfied hygienic requirements the supply for lecture and recitation rooms was put at 1500 cubic feet per hour per occupant; for physical laboratories, 2000; chemical laboratories, 3000; organic chemical laboratory, 4500. The flue areas of column four of the table are computed on an assumed velocity of air-flow of 400 linear feet per minute.

Practically, in all but the crowded rooms the individual supply largely exceeds this amount, since the dividing of classes into sections makes the number occupying the laboratories at one time comparatively small. Thus the large chemical laboratories, supplied with air for 150 students at one time, seldom have over half, and often but one-fourth, that number at work, resulting in an hourly allowance of from 6000 to 12,000 cu. ft. to each operator. The volume of air hourly moved through the building approximates five times the cubic capacity of its rooms, or an average of 8000 cu. ft. for each of its occupants, on the assumption that the students are equally divided between the two main buildings.

The boilers supplying the steam for the heating, and the engines furnishing the motive power for the fan and other machinery in the

Schedule.

Rooms. No.	Cubic Capacity.	Maximum No. Students.	Required Flue Area. Square Feet.	Cubic Feet Air per Hour.
2	20,000	15	1.50	36,000
3	15,000	10	2.50	19,000
4	40,000	50	6.00	144,000
6	28,000	15	1.00	24,000
			11.00	223,000
10	38,000	30	6.50	156,000
11	5,000	20	2.00	48,000
13	13,000	10	2.00	48,000
14	35,000	400	15.00	360,000
15	11,000	20	3.00	72,000
16	36,000	40	7.50	180,000
			36.00	864,000
20, 21	62,000	50	9.00	216,000
22	27,000	200	9.00	216,000
23	23,000	150	6.00	144,000
24	48,000	...	5.50	132,000
			29.50	708,000
30	9,000	35	2.00	48,000
31	17,000	70	3.50	84,000
32	11,000	40	3.00	72,000
33	8,000	25	3.50	84,000
34	11,000	3	2.00	48,000
35	27,000	200	9.00	216,000
36	23,000	150	7.00	168,000
37	13,000	15	3.00	72,000
38	17,000	70	3.00	72,000
39	18,000	30	3.00	72,000
			39.00	936,000
40	60,000	150	18.00	432,000
41	60,000	150	18.00	432,000
42	18,000	30	5.00	120,000
43	10,000	20	1.50	36,000
44	8,000	10	1.50	36,000
45	7,000	15	2.00	48,000
46	5,000	3	1.00	24,000
46A	4,000	3	1.00	24,000
47	4,000	3	1.00	24,000
47A	4,000	3	1.00	24,000
48	6,000	3	4.00	96,000
			54.00	1,296,000
	741,000	2,033	167.80	4,030,000

New Building, are in the Rogers Building, the steam pipes and shafting being hung in an underground tunnel of 90 feet length connecting the two buildings.

The fan (Fig. 3) is 12′ in diameter, 4′ deep, and has one mouth of 9′ diameter, and carries 12 curved, wing-shaped floats, which, as the fan is unhoused, discharge the air through the entire periphery into the room forming the sub-basement extension. Fixed at 93 revolutions per minute, the fan moves 1000 cu. ft. of air per second in mild weather, when the work of the fan is not assisted by the aspiratory action of the flues, at an expenditure of 14 H.P. In cold winter weather the volume of air moved, if all the inlet windows are open, may, but is rarely allowed to, reach 1500 cu. ft. per second; 1000 cu. ft. per second may then be moved with an expenditure of 6 H.P. The maximum plenum pressure produced by the fan is but little above one-eighth inch water column.

The working steam surface for the entire building is something over 6000 sq. ft., of which 2400 is in the main coil and 3600 in the supplementary system. The low average proportion of one sq. ft. of heating surface to 140 cu. ft of space contained by the building's walls is made possible only by the increased rate of condensation in the pipes because of the rapid movement of cool air over them, and the method of heating by large air volumes at low temperature rather than by small volume at high temperature.

The main coil is made up of eleven sections, one of which is shown in elevation in Fig. 4. These sections present in elevation a surface of 240 sq. ft., offering large area and small resistance to the movement of air. Nine of its sections are used for steam and two for cooling the condensed water returned through them from the steam sections.

For purposes of investigation and experiment, a daily meteorological record has been kept, as well as a record of condensation and coal consumption. Fig. 5 shows the method adopted for obtaining the condensation record. The condensed water is returned to an open tank, by gravity from the supplementaries, and by trap from the main coils, and pumped thence to the boiler tank in the Rogers Building. The working of the pump is automatically controlled by a counterpoised float which prevents the water in the tank falling so low as to admit air into the suction pipe to be registered as water. The stroke of the pump being of uniform length, it is used as a meter, the pulses of the piston working a connected pawl and ratchet which rotate a long screw carrying a nut with recording pencil. The pencil rests on a paper wrapped upon a drum which is rotated by clock-work once in twenty-four hours, tracing lines such as are shown in Fig. 6. This record gives the daily

condensation in cubic feet, the rate of condensation throughout the day, the time of putting steam on and shutting it off, and of starting and stopping the fan, and is a complete check on any attempt of an engineer to practise deception as a cover for delinquency or incompetence.

Some special arrangements deserve a more detailed notice than that already given them.

As indicated by the schedule, the chemical laboratories are located in the top story of the building — this story receiving one-third of the total air supplied to the five stories, the hourly supply to the large laboratories equalling seven times their cubic capacity. The actual supply to the analytical laboratory is one-fourth greater, the individual supply varying from 8000 to 20,000, according to the number of students occupying it. Most of the work usually ordered under hoods, such as the evaporation of acids, etc., is here done in the open room, to the students' great convenience and advantage, and without harmful or annoying effects.

The discharge ventilation of these laboratories is effected chiefly through the hoods, a sectional elevation of which appears in Fig. 7.

For every twelve feet of hood frontage there is a discharge flue of three square feet cross-section, the flue being connected with the hood by an aperture of equal area.

Within the hood is an inclined diaphragm of such width and placing as to leave a slot three inches wide along the whole front of the hood. Its location and inclination serve to protect the hood contents from injury by the falling of *débris* from the flue. The hood sash is prevented by stops from being raised beyond a fixed point, such that its lower edge shall be, according to the height and temperature of the hood, from four to eight inches below the outer edge of the diaphragm. The space between the glass of the sash and the face of the hood is cut off from the hood space by the raised sash, so preventing escape into the room of gases, etc., by that means.

The use of the diaphragm is apparent in extending and equalizing the current along the entire length of the hood. The direction of inclination given to it, and the front location of the slot, may not, however, be so apparently reasonable. The aim in the latter arrangement is to concentrate the discharge current along the line of most natural escape of warmed gases from the hood into the room, since all gases to escape must pass this line, which would not be true of a similar slot at the rear of the hood. The inclination given to the diaphragm is slightly upward from rear to front, in order that the initial upward movement may not

be completely and abruptly broken, so forming a deep stratum of fumes which might then escape at the lower part, because beyond the reach of the effective action of the discharge current, or else might cool and settle or be forced down along the rear walls at a point remote from the heating burner, and so escape.

Each of the two largest laboratories has sixty feet of such hood frontage, or fifteen square feet of outlet area, with a linear flow-rate of some five feet per second. The plenum condition of the laboratories, due to their top location, the levity of the warmed air, and the propelling action of the great fan, make a dual system of discharge ventilation possible without any of the risks attending such a method when the ventilation is effected by means of exhaust rather than plenum action. Other outlets are therefore provided, which, together with those of accidental nature, afford an aggregate area equal to that through the hood.

The method of ventilating the photometer room of the physical laboratories is shown in Fig. 8. In such rooms, designed for a number of students and for work involving the use of several gas or oil lamps, funnel-shaped hoods are placed over the burners, in addition to the floor and ceiling method of ventilation.

The object of this paper is the presentation of methods and results rather than a discussion of their merits. Yet a somewhat frequent challenging of the reasonableness of one of the methods employed, and the confusion of ideas, if not ignorance of facts, which has in some instances marked the discussion of the subject, may be accepted as the sufficient apology for a short digression in defence of the choice of methods.

The method of heating and ventilating rooms by passing a warm-air supply into them at the top and on their warm or inner side, and of removing the spent air through an aperture at the floor and on the same side of the room, was original, though it did not originate with the writer.

Stated with the least of possible argument or fulness, the reasoning which led to the adoption of this method was as follows: —

1. So far as practicable, it is economically advantageous that the movement of air through a room for the purpose of its ventilation should be one of mass, and of uniformity in direction and in velocity, since in so far as the air can be given such movement, the vitiation will be cumulative from the plane of entrance to that of discharge, the quantity of vitiated air within the room will be reduced to a minimum, and also the time of its retention and the limit of the space occupied by it.

2. In order to secure a vertical mass movement, the successive

strata making up the mass of air must have such temperatures as to maintain their stability of relative positions. If the movement is to be ascending or descending, the successive upward strata must, therefore, have an increasing temperature.

3. The upward movement is that to be employed for enclosures in which the air is warmed in transit, and the downward for those in which the air is chilled in transit.

Air is warmed in transit when the heat given to it is greater than that which escapes from it, as in the case of well-filled audience rooms where the wall surface to the individual is small, and especially when the auditorium walls are internal and therefore warm, and when the heat of illuminating flames is added to that of the audience. In this case the air is passed in at a temperature lower than the mean of the air in the room, and considerably lower than that at the ceiling, the point of escape. If admitted with slow movement through a multitude of floor inlets, it will spread itself out in a horizontal stratum at the floor, and as heated by contact with individuals making up the audience or by burning illuminants, it will rise, not to be brought back into recirculation.

Air is cooled in transit when the heat yielded to it within an enclosure is less than that escaping from it. This is the general winter condition prevalent in a cold climate and in rooms with exposed walls, whose surface per occupant is large, and the occupation within which is not accompanied with relatively excessive heat production. In this case, in order to secure the desired mass movement, the warm air must be quietly and in diffused form passed in at the top and stratified there, to settle as cooled and as withdrawn at the floor.

But mass movement by uniformly advancing strata is not practically possible, because of the disturbance due to the unequal heating or cooling effects of exposed surfaces. Thus in the case of heating in transit, individual currents rise from each occupant and burner with a greater initial velocity than that of the whole mass. The air moves from the floor largely in individual currents which merge into a mass movement at a height determined by various conditions of compactness of audience, number, and arrangement of light, etc. So, also, in the case of cooling in transit, the downward movement is almost wholly in that part of a room next to the chilling or outer walls. The most, therefore, that can be sought, is a concurrent movement which shall be of varying velocities, but without reversals.

Concurrent movement may be more easily secured in upward than in downward ventilation under the ordinary conditions favorable to

each, since under the best conditions none of the currents are interfering in the first case, whereas all individual currents from occupants and illuminants must be of an interfering nature in the second. The results of downward ventilation under conditions most favorable to it cannot therefore be made as theoretically perfect as those of upward ventilation under conditions equally favorable to it.

It by no means follows, however, that the substitution of the upward for the downward must prove advantageous. The adaptation of each to its own favoring condition yields the most perfect, though not equal results. If upward ventilation be substituted for downward where the conditions favor the latter, the warm and fresh air rising to the top of the room floats at the ceiling, forming a stratum whose movement is in two directions, one part going through the discharge aperture and becoming a total loss, and the other passing down the chilling walls. It is to be noted that in such rooms, as usually heated and supplied with air, the only air which gets down to the breathing line is that brought down practically by the same method as that relied on in downward ventilation, and that but a part of the total supply is thus brought down. Hence, in such a case, that which is antagonistic to the upward movement becomes the most efficient factor. The uniform upward mass movement is in this case interfered with by the individual currents of hot air from the inlets, which force their way to the ceiling and drag variable quantities of impure air with them, and by the rotation of the mass, due to the action of the chilling walls, which may take place once in every five or fifteen minutes, according to the exposure and shape of the room and the difference between inside and outside temperatures. But for these two accidental yet favoring and saving circumstances, it would evidently be possible, by the upward method of ventilation under the assumed condition, to crowd down and hold the cooler and vitiated air to the floor by the warmer and purer air as it forced its way to the ceiling and took exclusive possession of the outlets, a result more or less realized whenever upward ventilation is attempted under conditions favorable to the downward method. Further, air brought downward by this means would be more vitiated by its first passage through the lower strata than if the supply had been passed in at the top of the room.

The direct escape of unused air and heat, the reduced proportion of supply below the breathing line, the increased proportion of effluvia in the lower strata, and its longer retention, are the results of an upward ventilation of rooms in which the air is chilled in transit. The ends proposed at the outset are less perfectly realized than by a down-

ward method, which passes pure air in at the top, and by withdrawal at the bottom, forces the whole supply down to the breathing line before escape, and which secures a minimum of reversal in movement by making the artificial movement concurrent with the natural, and by making the rate of supply and discharge approximately equal to or in excess of the rate of downward movement along the cooling surface.

If, however, the air supply is small and its temperature high, the loss of air and heat through leakage at the ceiling may make a ceiling location of inlet inadmissible. In such case the inductive mixing and supplementary rotary action of the strong upward current of hot-air supply is needed to effect a warming of the air at the floor.

As usually heated, this is true of dwelling-houses and all rooms whose hourly air supply through provided channels is not equal to four times their capacity.

When otherwise advisable, the elevated position of the inlets has the further incidental advantages of preventing the low temperature currents being felt as draughts, and insures the cleanliness of inlet fixtures and conduits.

For the benefit of such as may use this description as an aid to the choice or adaptation of means, it may not be amiss to mention such defects in the system as would have been avoidable by a better adaptation of the building to a preconceived and adopted system.

The flue arrangement might have been made much more compact, outside flues avoided, the ability in all cases to locate inlets and outlets for the most effective and economic ventilation increased, the large area of the sub-basement and the required piping in mains and returns reduced, the height of the sub-basement increased, and the drainage and manipulation of the supplementary system and the control of the sub-basement temperature made more easy and complete. By the exclusion of all water and sewer pipes, the sub-basement temperature could be reduced to the lowest requirement of any room in the building.

The form of interior walls originally recommended for this purpose, and to which preference is still given, is shown in Fig. 9, the flues being 18″ square and the walls 30″ in thickness; the sub-basement of the three central portions being used for ventilation and having a greater depth than the other two, which could be devoted to other purposes.

The heat generated by the burning of some 500 cubic feet of gas per hour in the large chemical laboratories, the heat escaping from steam tables and other surfaces and the solar heat entering through the large window exposures, and the presence of the occupants, sometimes increases the temperature of the air passed through them from

20° to 25° F. If work is to be so generally done in the open rooms as at present, it should be possible to pass air into them at a much lower temperature than is admissible now, because of the consequent chilling of the basement.

The fan is single rather than double mouthed, as at first proposed, thus reducing the area at this point to such an extent as to make continuous running a necessity, the original intention being to use the fan only in mild weather. It can be run only at a fixed speed for all weathers, its rate being determined by that of an engine and shafting more or less linked with the whole machinery of the two buildings. The speed is fixed for the air required with an outside temperature of 50°, and the air-flow is regulated by the inlet doors used as dampers, a method not to be recommended on the score of economy of power.

The arrangement of by-pass dampers in connection with the supplementary system (Fig. 2), the construction of the supplementary coils, and the placing of heating surface within the exhaust flues were accepted without approval.

The cost of the heating and ventilating equipments is a further matter of practical interest. This may be said to begin with the space allowed to it in the sub-basement, in the cost of its extra depth, and in the basement floor, which otherwise would, according to the original plan, have been the concrete of the now sub-basement floor. The flues cost nothing, as the material saved and the cost of building a solid wall would have equalled that of the hollow wall with contained flues. The 240 registers and register faces and the supply and discharge flue dampers are an item of expense not included in a direct heating instalment.

The actual heating surface is about 8000 sq. ft., excluding that of distributing and return pipes, which are covered, or one square foot to each 110 cu. ft. of the building's contents. But some 1200 sq. ft. of this surface are in the 31 outside wall discharge flues, and have never felt the warmth of steam, and also 400 sq. ft. of the supplementary system under flues supplying air to the chemical laboratories are not used. The total surface used is, therefore, some 6400 sq. ft., or one square foot to 140 cu. ft. of contents, — a much less surface than engineers would be willing to risk in heating by the direct method, and considerably less than that reported for the Rogers Building so heated. This is made possible only by the method of heating by large air volumes at low temperatures, and the rapid rate of condensation within the pipes effected by the forced movement of cool air over them, the hourly rate at times exceeding two pounds per square foot in

the main, and one pound in the supplementary coils, against a mean of some four-tenths pound in ordinary direct exposure.

The saving in piping due to rapid condensation is sufficient to pay for the fan, together with an attached engine, had that arrangement been adopted.

The piping is concentrated in the sub-basement, and aside from the necessity of careful alignment, presents no special difficulties of construction. The sheet-iron work for boxing the supplementary coils, and the mason work about the main coils and fan are additional items of cost not involved in a direct instalment.

The original estimate for the complete outfit, including fan and large engine, was about $11,000, and there seems no reason why, at prices then current, that estimate was not a fair one for an instalment carefully planned in advance of construction. But the novelties in requirement and difficulties of construction, imperfectly met by improvised rather than matured plans, — resulting in experiments, errors, and costly remedies, — the connection with the boilers, 200 feet distant and in another building, the purchase and setting of a costly and high-power engine with its shafting through the tunnel, together with a very considerable amount of work done for the Chemical, Mechanical, and Mining Departments, made a total bill which cannot properly be charged to the necessary cost of introducing a system such as has been described.

[*To be continued.*]

Note. — The illustrations will be given in connection with the second portion of this article.

ELEMENTARY NOTES ON GRAPHIC STATISTICS.

By DAVIS R. DEWEY, PH.D.

I. Definition and Uses. — With the recent progress in statistical art or science there has been developed a method of illustration applied to statistics by means of lines, surfaces, and maps. Experience shows that statistics are made more luminous and are better understood by their graphic representation. An analogy may be found in the application of geometrical figures to algebraic formulæ. Graphic illustration in statistics has little significance or utility except where comparisons are to be made. For example, the drawing of a perpendicular line three inches high to represent, we will say, the three dollar per diem wages of a laborer, does not assist the thought in grasping the numerical conception three; but if it be desired to compare the wages of two laborers, the one receiving three dollars per day, and the other two, aid may be rendered by the use of lines or other symbolic representation. Just as the subject of statistics itself implies the treatment of more than one number, so the graphic method applied to this subject implies the comparison and differentiation in one view or picture of a number of facts of a numerical character.

Not only does the graphic method assist thought, but it may also be an instrument for the discovery of new truth. This may be illustrated by the following example: In the first place consider the number of deaths in Massachusetts in each quarter of the year 1885. When these are reduced to percentages, it is found that —

26.5 per cent died in the first quarter ending in March.
24.9 per cent died in the second quarter ending in June.
27.7 per cent died in the third quarter ending in September.
20.9 per cent died in the fourth quarter ending in December.

Suppose the investigator wishes to compare these percentages with the mortality statistics of previous years; examination shows that the distribution of deaths over the four seasons of 1885 bears a certain similarity to the distribution of deaths for the fifteen years, 1871–1885. The average percentages in the latter case for the whole period are: 24.4; 23; 29.1; and 23.5, respectively. In this case there is manifestly little

to be gained by the employment of graphic representation of these percentages. The mind readily perceives that the year 1885 was no exception to the rule of greater mortality during the summer months, and that in the other seasons there is some marked variation. Secondly, however, suppose that one wished to compare the mortality in Massachusetts by *months* instead of by quarters, and instead of comparing the mortality in one year with that of the averages of fifteen years, it were required to compare at one view the mortality in each and every one of the fifteen years with the average rate. It is obvious that it would be necessary to compare twelve columns each with fifteen rows of figures, and from such a table attempt to discover minute deviations and similarities in the various death rates of the several years. This it would be almost impossible to do: even the comparison of the percentages by quarters, thus reducing the table to four columns instead of twelve (but with the same number of rows), would not be an easy task. It demands a peculiar and exceptional natural gift as well as training to be able to visualize at once an extended collection of figures and at the same time judge of their meaning and force, even when the figures are arranged in orderly columns.*

A third advantage in graphic illustration of statistics, as suggested by Levasseur, is its use as an instrument of control. Mistakes in figures may be easily overlooked; but when these figures are placed in graphic form, the error becomes so glaring that it immediately arrests attention.† There is no need at this point of saying more of the utility of the method of graphic statistics; the increasing demand for statistical albums and atlases furnishes abundant testimony to its value.

II. History. — As in most arts, there is in this a dispute with regard to prior claims of discovery. According to Block,‡ this method was invented by William Playfair of England. At all events, Playfair regarded himself as the discoverer, for in the preface of a work published in 1821, entitled "A Letter on Agricultural Distresses," he advances this claim and refers to the "method invented nearly forty years ago of representing by charts or diagrams the progress and pro-

* See Block, Statistique, ch. 13, p. 401. Massachusetts Registration Report, 1885, p. 90. See, also, Walker's Statistical Atlas, p. 5, for remarks on the uses of charts and maps in the discovery of new relations.

† La Statistique Graphique, p. 33. Originally published in Jubilee Vol. of Lond. Stat. Soc., pp. 218–250.

‡ Statistique, pp. 401–404.

portional amounts of prices; that method having met with much approbation on the Continent, and Baron Humboldt having declared it to be the best mode of impressing on the mind proportional quantities." * Meitzen, however, refers to the similar work of a German in 1782–85 who apparently thus antedates his English colaborer.† The method was quickly adopted by others; it was brought to the attention of the International Statistical Congress which met at Vienna, and at the session of 1872 at St. Petersburg it was fully discussed in three exhaustive memoirs by Ficker, Schwabe, and Mayr.

III. The Method. — The ways by which statistical matter can be represented in graphic form are numerous. During the past few years these various devices have been roughly classified under different technical names by European statisticians; and although these names are purely arbitrary, it is more convenient and satisfactory to borrow the foreign terminology.‡ These methods may be divided into two principal classes known as: —

A. DIAGRAMS.

B. CARTOGRAMS.

Further, diagrams § are distinguished as follows: —

1. *The dot or point.* — The grouping of dots or points in certain numbers in order to make statistical comparisons is probably the simplest possible method which can be devised. This is, however, too simple a device to be of much practical application. It is generally used in combination with cartography, or may be used independently, as in the required comparison of the relative density of population per square mile in two given countries or districts. Let arbitrary areas or squares be constructed, all of equal size, to represent the square mile, and in the several squares distribute as many dots as there are units in the population densities per square mile respectively.‖

* Page iv. † Statistik, p. 24.

‡ For classifications, see Haushofer, Statistik, p. 47; Block, p. 404; Levasseur, p. 3; Meitzen, p. 166; Mayr. In Walker's Statistical Atlas, p. 2, the distinction is made between Geometrical and Geographical illustrations.

§ According to Block, the two statisticians who made the most frequent use of this were Schwabe and Mayr, who were the first to trace their theory. See Compte Rendu du Congrès de St. Petersburg, 1872. Also in vol. of Permanent Commission, 1876. A theoretical essay was presented to the Congress in 1857, but appears rudimentary.

‖ Levasseur in his monograph, La Statistique Graphique, notes this method, pp. 3, 4. See, also, Mayr, in Commission Permanente du Congrès International de Statistique, Memoires, St. Petersburg, 1876, pp. 66, 67. Illustration of this method is furnished, and its utility shown. In Scribner's Statistical Atlas there is a good example of its use in representing the distribution of schoolhouses in Indiana in 1853 and 1880 by counties. Page lix.

2. *The line.* *a. Straight.*

See Levasseur, Stat. Grap. 4–6; Block, 403–406; Mayr, as above, 68–76.

The use of the line is a simple method of presenting a series of facts of the same nature; either the horizontal or the perpendicular line can be used, but the latter is preferable. Upon a horizontal line used as the base or axis (line of abscissas), erect a number of perpendicular lines proportional to each other in the same ratio as are the numerical facts to be represented. The length of the axis may be graduated or entirely arbitrary. For example, in the illustration of the populations of several countries, it is necessary to graduate only the ordinates, these being placed at equal distances from each other. Generally, however, the axis as well as the ordinate is employed to represent a definite fact, as in the illustration of the fluctuations of price, it is graduated to indicate units of time. It is always customary to employ this for the representation of the time-unit.

b. Curved. — The graphic art, however, goes farther than the mere erection of ordinates. It is customary to connect the termini of the perpendicular lines by another line, which will naturally be irregular in its course. This is termed a curve; and it makes the representation much more vivid. This device is especially necessary when it is desired to compare the simultaneous movement of several phenomena, or in a comparison, coincident in time, of births, deaths, and marriages. "It enables us to see at a glance not only the general character of the change in each of these amounts, but also the relations in which the changes in one element stand to another. It calls our attention to sequences and coincidences of time, and prompts us to seek for the concealed connection between them." "Historical curves supply in the most convenient possible form one set of the factors used in every explanation of the past and forecast of the future, in so far as it is based on an estimate of quantity." *

Due care must be taken not to distract the eye by the use of too many curves in the same chart. The purpose of many charts is entirely destroyed by thus encumbering the representation by a great variety of lines which it is difficult to follow. It is better to separate the phenomena and make two or more charts to represent the subject-matter. Assistance is rendered to the eye by distinguishing the curves by color as well as by form. The use of a broken line, the succession of dashes and dots, etc., will suggest great variety to the chart-maker.

* Marshall, On the Graphic Method of Statistics. Jubilee Vol. London Stat. Soc., pp. 252, 256.

"The chief advantage of this method," it is stated in Walker's Statistical Atlas, "is that it enables the eye to make very minute measurements, at single points, of the dimensions of the different subjects under treatment. Thus, with a perpendicular of the length taken for the figures . . . a preponderance of one-half of one per cent is easily shown. The limitation of this method is found in the fact that but a few subjects can thus be shown together, without the eye becoming confused, and losing its clue, its thread, as it passes across the figure from side to side.

"The use of alternating light and heavy lines, of continuous, of broken, and of dotted lines, and the printing of lines in different colors, will do much to postpone this result; yet, after all is done that can be done to extend the capabilities of this method, it fails in representing any large number of statistical subjects together." Page 2.

If but one curve is employed, the effect may be increased by shading or coloring solid the entire portion between the curve and the line of abscissas, thus bringing it out in strong contrast; if two or three curves are in use, the same device may be employed with corresponding gains by the use of appropriate colors or tints.* Beyond the use of three or four colors in areas, however, it is not wise to go, as confusion results.

A further application of the curve, "whenever a statistical subject consists of two parts approximately equal, as male and female, is made by erecting a perpendicular, and from this bilateral ordinates are drawn at equal distances from each other, the ordinates on one side being devoted to, say, the male, and the others to the female element, and the several ordinates on the one side and on the other being determined as to length by the statistical proportions to be represented." The outer ends of the ordinates are then connected, and thus a closed figure is formed. Such diagrams are frequently employed in reports of Life Insurance.†

Curves are fully discussed by Professor Marshall in a monograph, "On the Graphic Method of Statistics," Jubilee Vol. Lond. Stat. Soc., pp. 251–260. Although he strongly recommends their use, and even prefers the "large collection of historical curves as a standard gauge, perhaps bound up in a book or books," he calls attention to certain defects which suggest misleading notions. This is especially so in the attempts to represent comparative rates of growth of different things,

* See Census of 1880, Vol. Mortality, Part I., pp. xxx.–xxxix.; also Plate I. folded in the back of the volume.

† Walker's Statistical Atlas, Plate XLVII., with a series of forty-seven figures. Bull, L'Institut Intern. de Stat., Vol. I. (1886), pp. 189, Plates illustrating the population of Italy according to sex.

rather than absolute amounts of increase. Often two curves appear to show entirely different rates of increase, when in reality they are almost identical, as can be shown by a change of scale. For example: in the comparison of the consumption per head of tea and sugar, an erroneous conclusion might be drawn from comparing a pound of sugar with a pound of tea. It is better to make the scale for tea in ounces.*

Circular Closed Axis. — Besides the use of the circle as a surface illustration, of which a description is given under The Circle, there is often employed what may be called "the closed line," in which the axis of abscissas instead of being a horizontal line is curved into a circle. This method is frequently applied in comparing cyclical phenomena which vary with the seasons of the year. Here the closed axis is divided into equal spaces of time, usually four or twelve for the seasons or months respectively. The ordinates are erected from a common point, the centre.

According to Dr. Farr, who in 1849 speaks of this circular diagram as a "new form," this device originated in the office of the Registrar General of England. "Mr. Glaisher had represented the mean temperature of each day of the year by a curve laid down in the usual way on a straight line, and it appeared natural to join the two ends of the line by substituting the radii of a circle for the ordinates, and the angular division of the circle for the abscissas." †

It was used with great success by Dr. Farr in his celebrated Report on Cholera in England, in numerous diagrams to show the temperature and mortality of London for each week of the period 1840–1850. Interesting and novel diagrams are also found in the same volume comparing the mortality in the cholera year, 1849, with the mortality in the five great plagues, 1593–1665. The significance of this diagram is heightened by drawing a circle with a radius equal to an average ordinate computed for the whole year, and then appropriately coloring the space within and without the circle as the termini of the ordinates for the several weeks or months fall within or without this normal radius.

The contrast thus produced exhibits the course of the phenomena in a striking manner.‡

* The mathematical law is stated at length by Professor Marshall on p. 258. Additional criticism by Dr. G. B. Longstaff is found on p. 268.

The curve is so generally employed in illustration that there is no need to refer to many special examples. See Atlante Statistico del Regno D' Italia. Review of the Chief Branches of Trade and Manufacture in Russia, in graphic tables arranged by D. A. Timiriazef. 1876.

† Report of Registrar-Gen. on Cholera in England, 1848–49, pp. xlvi.–xlix.

‡ For further illustration, see U. S. Census of 1880. Mortality, Part I., p. xlv., for Deaths by months in Massachusetts and in New Jersey. Also Part II., pp. xxxii., xxxv., xxxviii., and frequently.

The closed axis is sometimes objected to on the ground that it is difficult for the eye to measure radii with precision.*

3. *Surface Figures.*

See Block, 408; Mayr, as above, 76–79; Haushofer, 50; Levasseur, p. 6.

The surface figure or area may often be used advantageously instead of the line for the purpose of illustration. Here it is possible to use colors and shaded tints; and for indicating several facts at one view, the surface may be broken up in one of the following ways: —

a. By shaded lines drawn in different directions.

b. By black surface as a background pencilled with white lines. (Levasseur, p. 7.)

c. By colors, when care must be taken not to use a great number of colors, as they may become confusing. Further suggestions in regard to employment of colors are given under cartography.

The form of the surface used is of some importance, and choice lies between the use of the square, the parallelogram, the rectangle, the triangle, and the circle. Polygons may be left out of consideration, as they are rarely employed.

a. The Square. — This has been effectively employed in the French Album de Statistique Graphique, published by the Minister of Public Works, for the illustration of transportation statistics, by showing at a glance the relations between the number of passengers and the merchandise tonnage for each railway station. The square is first divided into as many rectangles as there are railway systems centring at a given station; and each resultant rectangle is subdivided into parts proportional to the amount of tonnage and number of passengers.† As pointed out by Block, there is one objection to the use of the square, in that it is difficult for the eye to judge accurately of the relationship between many squares. The same objection applies still more to the circle. It is easy to see that one is larger than the other, but the exact ratio eludes the eye.‡

b. The Circle — As the square is broken up into rectangles, so the circle is subdivided into appropriate sections. This device is in frequent use. An extensive series is given in Walker's Statistical Atlas, Plates

* Jubilee Vol. Lond. Stat. Soc. Remarks by Dr. G. B. Longstaff, p. 269.

† See Planche 5, Album de Statistique, 1886.

‡ Block, p. 408. See illustration of the various kinds of indebtedness of the United States, as shown in Plate VI., Vol. VII., U. S. Census of 1880 (opposite p. 281). If the figures were not added, few readers would conjecture from a comparison of the squares, that the public debt was nearly twice as large as the state and local debt.

LI.–LXIV.;* and an example is again furnished from the Album de Statistique, where it is employed in the representation of the gross receipts of railway stations. The circle is divided into as many sectors as there are roads, and the area of each sector is made to the total area as the gross receipts of each system respectively is to the total gross receipts of the station. Each railway has its own conventional color, and light shades represent passenger receipts, while dark shades are employed for freight receipts.†

c. The Isosceles Triangle. — (Block, 408, 409.) This is preferable to the square or circle for the more vivid representation of numerical ratios, especially where the triangles are arranged on the same base lines. The vividness of the representation is heightened in proportion as the bases of the several triangles are contracted, thus approaching in this respect to the effect produced by perpendicular straight lines. Mayr recommends its use in the illustration in the same figure of the relation of several facts, where it is desirable to indicate numerical increments, slight but nevertheless important.‡

d. The Parallelogram. — (Block, 409.) The employment of this figure is very similar to that of those already mentioned. Block gives it preference. Generally the illustration would consist of narrow figures, equal in width, erected perpendicular on the same axis.§

Closely allied to this device is the use of bands of various widths applied to maps. This is effective in the representation of transportation statistics, such as gross and net receipts of railways, the number of passengers carried, railway and river tonnage. Suppose, for example, in a given railway system between Boston and Chicago, the gross receipts between stations A and B equalled $1000 per mile in a given period of time. If the scale be one inch width of band per $1000

* See also the paragraph in Atlas, in explanation of these diagrams, pp. 2, 3.

† Album de Stat., Planche 3. Various facts concerning the mining industries of the United States are illustrated by the circle. See Census, 1880, Vol. XV., pp. 33–38. None of these are colored. Notice the defective attempt at comparison of 1870 and 1880, by means of an inner and outer circle. Also colored Plates IX., X., et al., XXIII.

In the Zeit. des Preus. Stat. Bureaus, Vol. XVII., 1877, p. 196, is another application of the circle for the comparison of population densities. The series of circles are broken up into hexagrams according to the territorial densities respectively.

‡ If the increments are large, it is an unsafe method to follow unless narrow bases are employed. See, for example, Census 1880, Vol. VII., Plate III., in which the Increase and Decrease of National Debts is represented by a series of isosceles triangles. From the study of the diagrams alone, few would conclude that the national debt of Turkey was three times that of Portugal. The heights of the two triangles are in the ratio of two to one.

§ Excellent examples of the comparative use of the parallelogram are found in Walker's Statistical Atlas, Plates XXXI., XXXII.

receipts, the band upon the map between these two points will have a width of one inch for the distance A to B. If the receipts for the next division, B to C, were but two-thirds as much, the band for that space will be but two-thirds of an inch in width.*

e. The Solid. — (Mayr, 79, 80; Levasseur, 30, 32.) The representation of statistics by figures of three dimensions is rarely used. The best examples of it are those prepared under the direction of the Italian government. Although they may ingeniously combine a number of facts which could not otherwise be represented, yet one of the chief advantages of graphic representation is lost, — clearness.†

B. CARTOGRAMS. — Haushofer, pp. 50, 51; Block, pp. 410–418; Levasseur, pp. 18–30.

These exhibit statistical expressions by means of maps or territorial delineations. Cartography is the employment of geography for the graphic illustration of statistics. It is used advantageously in comparing states, countries, or other political divisions with reference to any statistical fact. Although cartograms may represent absolute numbers, they are generally employed to express ratios. Relative facts are desired, and in particular the difference as compared with the average. (Cheysson.)

Levasseur classifies cartograms in four varieties: —

1. Maps with surface diagrams.
2. Maps colored according to territorial divisions.
3. Maps with curves.
4. Maps in relief.

1. *Maps with surface diagrams.* — This is a common form of the application of cartography. Geometrical figures, as circles, squares, etc., are distributed over the map, the figures being proportional in their areas to the numbers under consideration.‡ A favorite example of this in European statistical albums is the representation of transportation statistics of different countries. The length of railroad of each state is represented by horizontal lines, traced on each state; while proportional bands of varying width, following the location of the railroad systems, may illustrate the tonnage or expenses of operation. In a recent graphic album this method has been used to represent the increase or diminution of population in each department of France.

* See Album de Statistique, 1886, Planche, pp. 1, 2.

† See Levasseur for an illustration of the method of the Italian government, p. 34.

‡ See map exhibiting the distribution of various sects in Prussia, by means of circles. Zeitschrift Preussischen Statistischen Bureaus. Vol. XXII. (1882), p. 294, Table III.

2. *Colored maps.* — The color and shading here represent the numerical ratio to be expressed. An example is in the representation of the degrees of illiteracy or literacy in the different parts of the country by means of colors. It is a popular method of illustration;* but apt to be inaccurately applied, and thus misleading.

The difficulty as clearly pointed out by Levasseur and Cheysson, in two recent monographs† is in the classification of the facts to be expressed.

Before, however, proceeding to a discussion of this, it is desirable to distinguish between (*a*) the monochrome and (*b*) the polychrome methods.

By the first, the various intensities of the ratios are represented by several tints of one color, effected either by paints or hatching; in the latter, two or more distinct colors are used, and these may be tinted to express varying degrees of intensity. Levasseur is strongly in favor of this system. The red color is applied to all territorial divisions where the fact considered is above the general average; while the blue color is confined to the expression of facts below the average. It obviously offers a greater number of classifications than is permitted by the monochrome method, and it is claimed, therefore, that the thought of the illustration is more easily seized. It is always a question, however, where the dividing lines shall come which shall determine the use of the red or of the blue. In a given series of twelve categories it may be misleading to use the ratio 50 per cent as the distinguishing feature.

Thus Cheysson criticises its use on the ground that territorial divisions which were in reality but little removed from the average were represented as different in too marked a manner. He therefore in 1878 proposed to employ a third color for the average zone, or to leave it in white. Levasseur hesitates to adopt this, because it may increase the

* Some excellent early examples of this method are found in Essai sur la Statistique Morale de la France, by A. M. Guerry, published in 1833. See maps representing crimes against persons, crimes against property, education, etc. An advance in technical execution is shown in similar plates prepared by the same author in 1864, published in the great work Statistique Morale de L'Angleterre comparée avec La Statistique Morale de la France. In combination with these latter maps there is used a great variety of symbols ingeniously applied for the expression of minor points of interest. Colored maps, illustrating a wide range of social and economic subjects, are furnished in the well-known Statistical Atlas of the United States (1870), by Francis A. Walker; and in Scribner's Statistical Atlas (1880).

† Les Cartogrammes a teintes graduées: Système de classification rendant comparable les divers Cartogrammes d'une même série. By M. E. Cheysson. Presented to the Societé de Statistique, Feb. 16, 1887, pp. 7.

La Statistique Graphique. By E. Levasseur. Papers published in Revue Geographique, 1887. A different article from that referred to previously, of the same title.

cost of the impression and detract from the simplicity of the illustration. He suggests, however, that the category of the "least red intensity" and the category of the "greatest blue intensity" should be marked in common by black points, which will thus give them a common significance.

Turning once more to the principle of classification to be adopted in the selection of ratios, suppose, for example, it is desired to represent the illiteracy of the United States by seven groupings. What should be the scale?

In Scribner's Statistical Atlas, Plates 50, 51, the following scale for "Persons unable to read to total persons" is employed:—

(*a*) under 2 per cent;
(*b*) 2 to 4 per cent;
(*c*) 5 to 9 per cent;
(*d*) 10 to 24 per cent;
(*e*) 25 to 49 per cent;
(*f*) 50 to 74 per cent;
(*g*) 75 per cent and over.

By this it will be observed that states or sections which have 10 or 24 per cent of illiteracy respectively will be pictured alike; whether, however, two states with these respective ratios do not consequently sufficiently differ in their grade of intelligence and civilization as to warrant a distinction in the cartogram, is open to question.

Another difficulty occurs where it is desired to make a series of cartograms representing a series of homogeneous facts. Shall each of the cartograms in the series be constructed according to its own individual character without regard to the whole, or shall there be a uniform system? (Cheysson.) If the former method be followed, it may result that the same tints will indicate different absolute coefficients.* For example, in Plate 113 of Scribner's Statistical Atlas, in two different maps on the same page, representing the number of horses on farms, and the number of sheep on farms, per square mile respectively, the same tint is used for "16 and over" in the one case, and for "40 and over" in the other. To obviate such a misconception Cheysson proposes that there should be substituted for absolute coefficients their differences by relation to a general average.

Let the local or individual coefficient be d; the general average m; then the proportional difference will be $e = \frac{d-m}{m}$. Use the values of e in the cartogram in place of the absolute coefficient.

The application of the cartogram is limited; no scale of degrees of color can be devised which will suitably compare extremes which vary

* See criticism of Dr. G. B. Longstaff, in Jubilee Vol. Lond. Stat. Soc., p. 268. Other difficulties in the construction of scales for cartograms are indicated in Walker's Stat. Atlas, p. 4.

by a wide difference, as, for example, the relative density of population in New York City and in the State of Vermont.*

3. *Maps with curves.* — Maps with isothermal lines are illustrations of this method. It is in general use in meteorology, but it can be applied as well to the needs of social science. For example, there has been prepared in France a map of the density of the population of Paris. It is obvious that to construct such a map it is necessary to learn the population of the city by very small units of area; when the statistical returns are thus given, the method is possible and suggestive.†

4. *Maps in relief.* — Here again the density of population may be represented by elevation or depression from the normal surface of the map, in the same way as are physical variations. To the general use of such maps there is open, however, the objection of expense and difficulty of circulation.

* In addition to the works already referred to, for further examples of this form of cartograms, see: —

United States Census, 1880, Vol. Population.

Der Boden und die landwirthschaftlichen Verhältnisse des Preussischen Staates nach dem Gebietsumfarge vor 1866. Atlas. By August Meitzen, Berlin, 1871 (18 Tables).

Atlas Physique, Politique, Economique de la France. By E. Levasseur.

Atlas über die Entwicklung von Industrie und Handel der Schweiz. By Dr. H. Wartmann.

The Statistical Atlas of England, Scotland, and Ireland. By G. Phillipps Bevan, 1882.

Similar cartograms are to be found in later issues of the Zeitschift des Preussischen Stat. Bureaus.

Bulletin de L' Institut International de Statistique, Vol. II. (1887), p. 242. Population map of the world by Levasseur, in but one color, tinted.

† Levasseur, p. 28.